MEC17

A SENSE OF WHAT'S TO COME

Myoelectric Controls and Upper Limb Prosthetics Symposium

August 15-18, 2017

Fredericton, New Brunswick, Canada

Conference Program

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Institute of Biomedical Engineering

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Note: This document contains abstract submissions only. The full conference proceedings are included on the USB key in your delegate kit. They are also available on our conference website.

Welcome to MEC17

On behalf of the organizing committee and the staff of the Institute of Biomedical Engineering at the University of New Brunswick, we would like to welcome you to MEC17. We are pleased to present a diverse and thought-provoking assortment of scientific papers and discussions relating to the field of myoelectric control and upper limb prostheses. Our theme for this year's symposium is "A Sense of What's to Come" which, aside from its direct meaning, also acknowledges the growing number of papers on sensory feedback.

Speaking of feedback, we have acted on the feedback we received during MEC14 and hope that we will continue to provide that delicate balance between a rigorous scientific program and a reunion of our tight-knit "family". In both regards, we eagerly welcome new faces to MEC.

This year's keynote speakers will highlight many of the advances in research and technology in issues pertaining to upper limb prosthetics.

- Dario Farina, PhD, is Full Professor and Chair in Neurorehabilitation Engineering at the Department of Bioengineering of the Imperial College London, UK. His research focuses on neurorehabilitation technology, neural control of movement, and biomedical signal processing and modelling.

- Jeff Tiessen is an amputee of nearly 40 years and is President and Publisher of Disability Today Publishing Group. He is a strong advocate for amputees living with limb loss.

- Doug Weber, PhD, is Program Manager in the Biological Technologies Office at the Defence Advanced Research Projects Agency, where he is managing neuroscience and neurotechnology programs.

The goal of the symposium is to share information, generate discussion, and inspire future research which will benefit all upper limb amputees.

We hope you will join us for the conference social events on Tuesday and Thursday, August 15th and 17th. Social events are an important part of MEC, as they allow time for informal networking and discussion of the day's events, while experiencing some of Fredericton's Maritime hospitality.

Once again, welcome to MEC17. Please don't hesitate to ask questions to any of our staff members.

Wendy Hill   Jon Sensinger

Co-Chairs MEC17

MEC17 Organizing Committee

Dan Blustein

Kristel Desjardins

Kevin Englehart

Satinder Gill

Wendy Hill, Co-Chair

Ashkan Radmand

Erik Scheme

Jon Sensinger, Co-Chair

Christine Stewart

Adam Wilson, Scientific Chair

Vendors will present products from:

Poster Sessions

There will be three poster sessions: Session A on Tuesday, August 15th at 2:45; Session B on Wednesday, August 16th at 2:45; and Session C Thursday, August 17th at 2:45.

These sessions will occur during the afternoon breaks on all three days. The poster session will begin with each presenter having one minute at the podium to describe their work. Presenters will then proceed to their posters, where they will be available to answer questions until 3:45PM.

The list of posters and presenters can be found in the following program pages.

Student Paper Competition

All students who have indicated that they wish to take part in the student paper competition will have their work judged to determine the quality of their presentation and the contribution of their work to the field. Judges have been chosen to ensure fair assessment of the technical and clinical relevance of each student's work. The top three podium and poster presenters will be awarded cash prizes. Prizes will be awarded during the Banquet Dinner on Thursday evening.

Social Events

touch bionics BY ÖSSUR

Welcome Wine and Cheese Reception
Tuesday, August 15th, 7:00PM-9:00PM
Beaverbrook Art Gallery

On Tuesday, August 15th, we will host a welcoming wine and cheese reception at the Beaverbrook Art Gallery, sponsored by Touch Bionics by Össur. Self-guided tours of the gallery will be offered along with a variety of hors d'oeuvres and beverages.

Two complimentary drink tickets are provided in your lanyard.

Transportation to and from the gallery will be provided.

ottobock.

Banquet Dinner – Maritime Kitchen Party
Thursday, August 17th, 6:30PM-11:00PM
UNB Currie Centre

Sponsored by Ottobock, our popular banquet dinner will be held on Thursday, August 17th at the UNB Currie Centre.

Frantically Atlantic, a Maritime duo, will be performing during the lobster dinner, and will be inviting all to participate and learn some new instruments. They will then facilitate an open mic circle where MEC participants with "musical skills" step up to the mic. All are welcome to join in, whether to lead a song or two, or just as moral support.

A cash bar will be available. Transportation to and from the banquet dinner will be provided.

Keynote Speakers and Invited Guest Lecturer

Doug Weber
Tuesday, August 15th
9:15AM-10:15AM

Doug Weber, PhD, is an Associate Professor in the Department of Bioengineering at the University of Pittsburgh. Dr. Weber is also a Program Manager in the Biological Technologies Office (BTO) at the Defense Advanced Research Projects Agency (DARPA), where he is managing a portfolio of neuroscience and neurotechnology programs.

Invited Lecturer: Munjed Al Muderis
Tuesday, August 15th
3:45PM–4:30PM

Associate Professor Munjed Al Muderis is an orthopaedic surgeon and a clinical lecturer at Macquarie University and the Australian School Of Advanced Medicine. He specialises in hip, knee, trauma and osseointegration surgery. He is a fellow of the Royal Australasian College of Surgeons and Chairman of the Osseointegration Group of Australia.

Jeff Tiessen
Wednesday, August 16th
9:15AM-10:15AM

Jeff Tiessen, an amputee of nearly 40 years, is president and publisher of Disability Today Publishing Group (DTPG), and a disability community pioneer and leader for over 25 years. Tiessen is a three-time Paralympic medallist and world record holder, award-winning journalist , and Canadian Disability Hall of Fame inductee. He is a respected advocate and is keenly aware of the informational needs of Canadians with limb loss through personal experience and a vast network of amputee colleagues, O&P practitioners, and industry partners.

Dario Farina
Thursday, August 17th
9:15AM-10:15AM

Dario Farina, PhD, is currently Full Professor and Chair in Neurorehabilitation Engineering at the Department of Bioengineering of the Imperial College London, UK. He has previously been Full Professor and Director of the Neural Engineering Research at Aalborg University, Aalborg, Denmark, (until 2010) and Full Professor and Founding Director of the Institute of Neurorehabilitation Systems at the University Medical Center Göttingen, Georg-August University, Germany (2010-2016). His research focuses on neurorehabilitation technology, neural control of movement, and biomedical signal processing and modelling. He was the President of the International Society of Electrophysiology and Kinesiology (ISEK) from 2012-2014 and is the current Editor-in-Chief of the Journal of Electromyography and Kinesiology.

Notice Regarding Audio/Visual Recording and Photography of Events

University of New Brunswick Institute of Biomedical Engineering (UNB IBME) may elect to take photographs of people and events during the MEC17 Workshops, Symposium, and Networking Events from August 15th to 18th, 2017. By attending MEC17, you agree to permit UNB IBME to use your likeness in these photos in promotion of the conference. The release checked off when registering indicated that you agree that UNB IBME shall be the copyright owner of the photographs and may use and publish these photographs. UNB IBME is released from any and all claims and causes of action that you may have now or in the future based upon or in connection with photographs and UNB IBME's use of the photographs in any manner. All rights granted to UNB IBME by you in the Release are irrevocable and perpetual. You waive all rights to any equitable relief in connection with the Release and the subject matter of the Release.

ABC Education Credits

Fifteen continuing education credits from the American Board for Certification in Orthotics, Prosthetics, and Pedorthics will be available to those attending MEC17 from August 15-18th. For each morning and afternoon session, a sign-up sheet will be at the Registration Desk. A Certificate of Attendance from IBME will be mailed to delegates in the fall.

In Memoriam: Professor Robert N. Scott (1933-2014)

In the time since MEC14, we lost a remarkable person. Our founder, colleague and friend, Bob Scott, passed away on December 22, 2014. The impact of his life's work cannot be overstated; his tremendous vision and dedication created an Institute and a legacy that has enriched many lives, including the amputees that have benefited from his pioneering work and the students, guided by his extraordinary mentorship, who have become leaders themselves. Bob's passing has left a void in many of our lives, professionally and personally.

A ceremony was held on October 5, 2015, with a large contingent of Bob's family, to dedicate a tree in Bob's memory. The Bob and Joan Scott Scholarship has been established, which will be awarded annually to a deserving student entering graduate studies at IBME. Bob's beloved wife, Joan, passed away in October 2016. She was as dedicated to our Institute as was Bob. The Scott family is very proud of Bob and Joan's dedication to UNB, and remain closely engaged with our Institute as his work continues to be carried out.

Professor Scott was instrumental in creating what is now MEC. In 1970, the first "Short Course" was held that would eventually evolve into MEC. It was entitled "Non-Diagnostic Electromyography in Physical and Occupational Therapy: Kinesiology and Myoelectric Control." In 1972, the first Myoelectric Controls workshop was held, with participation by orthopaedic surgeons, prosthetists, therapists and engineers. In 1993, the meeting adopted the current format of combined course and symposium.

Please join us in a moment of reflection of the tremendous contributions of Bob Scott.

Sincerely,

Kevin Englehart, PhD
Director, Institute of Biomedical Engineering
University of New Brunswick

Financial Support

The Institute of Biomedical Engineering and the MEC17 Organizing Committee gratefully recognize the following organizations for their contributions to the symposium.

TIMES	TUESDAY AUGUST 15	WEDNESDAY AUGUST 16
8:00 am	**Buffet Breakfast (60mins)**	**Buffet Breakfast (60mins)**
8:30 am	**Vendor Workshop: Ottobock (30mins)**	**Vendor Workshop: Coapt (30mins)**
9:00 am	**Welcome Address**	**Housekeeping**
9:15 am	**KEYNOTE: Doug Weber (60mins)**	**KEYNOTE: Jeff Tiessen (60mins)**
10:15 am	**Nutrition Break/ Vendor Displays (30mins)**	**Nutrition Break/ Vendor Displays (30mins)**
10:45 am	Paper Session #1 7 papers **PAIN: 3 / SENSORY FEEDBACK: 4**	Paper Session #3 6 papers **MYO CONTROL: 4 / CLINICAL PROSTHETICS: 2**
12:00 noon	**Lunch Break/ Vendor Displays (60mins)**	**Lunch Break/ Vendor Displays (60mins)**
1:00 pm	Paper Session #2 9 papers **MYO CONTROL: 4 / CLINICAL PROSTHETICS: 2 / OCCUPATIONAL THERAPY & OUTCOME MEASURES: 3**	Paper Session #4 8 papers **MYO CONTROL: 3 / PROSTHETIC DEVICES: 5**
2:45 pm	Fast-track Poster Presenters at Podium **Nutrition Break/ Vendor Displays** **POSTER SESSION A (60mins)**	Fast-track Poster Presenters at Podium **Nutrition Break/ Vendor Displays** **POSTER SESSION B (60mins)**
3:45 pm 4:00 pm 4:30 pm	**INVITED LECTURE: Munjed Al Muderis**	Paper Session #5 6 papers **OCCUPATIONAL THERAPY & OUTCOME MEASURES: 6**
5:00 pm	**End of Day Comments / RN Scott Tribute**	**End of Day Comments**
7:00-9:00 pm	**Wine & Cheese Reception** at Beaverbrook Art Gallery (*transportation provided*)	

TIMES	THURSDAY AUGUST 17	FRIDAY AUGUST 18
8:00 am	**Buffet Breakfast (60mins)**	**Buffet Breakfast (60mins)**
8:30 am	**Vendor Workshop: Touch Bionics (30mins)**	**Vendor Workshop: Infinite Biomedical (30mins)**
9:00 am	**Housekeeping**	**Housekeeping**
9:15 am	**KEYNOTE: Dario Farina (60mins)**	Paper Session #9 4 papers **MYO CONTROL: 4**
10:15 am	**Nutrition Break/ Vendor Displays (30mins)**	**10:00 a.m. PANEL DISCUSSION: 3D Printing (60mins)**
10:45 am	Paper Session #6 6 papers **OTHER: 3 / PROSTHETIC DEVICES: 3**	**Nutrition Break/ Vendor Displays (30mins)**
12:00 noon	**Lunch Break/ Vendor Displays (60mins)**	Paper Session #10 6 papers **CLINICAL PROSTHETICS: 2 / PROSTHETIC DEVICES: 4** **CLOSING REMARKS**
1:00 pm	Paper Session #7 9 papers **MYO CONTROL: 4 / SENSORY FEEDBACK: 5**	**Boxed Lunch/ Vendor tear down**
2:45 pm	Fast-track Poster Presenters at Podium **Nutrition Break/ Vendor Displays** **POSTER SESSION C (60mins)**	
3:45 pm	Paper Session #8 6 papers **OCCUPATIONAL THERAPY & OUTCOME MEASURES: 2 / CLINICAL PROSTHETICS: 4**	
4:00 pm		
4:30 pm		
5:00 pm	**End of Day Comments**	
6:30-11:00 pm	**Banquet Dinner** at Currie Center, UNB campus (*transportation provided*). Student paper awards	

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Tuesday, August 15, 2017

Grand Ballroom – Delta Hotel

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9:15AM-10:15AM	Keynote Address: Doug Weber
10:15AM-10:45AM	Nutrition Break / Vendor Displays
10:45AM-12:00PM	Paper Session #1
12:00PM-1:00PM	Lunch Break / Vendor Displays
1:00PM-2:45PM	Paper Session #2
2:45PM-3:45PM	Poster Session A: Fast-Track Presenters at Podium Nutrition Break / Vendor Displays
3:45PM-4:30PM	Invited Lecture: Munjed Al Muderis
4:30PM-5:00PM	End of Day Comments / RN Scott Tribute
7:00PM-9:00PM	Wine and Cheese Reception – Beaverbrook Art Gallery (transportation provided)

Paper Session #1 - 10:45AM-12:00PM

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Nutrition Break / Vendor Displays

2:45PM-3:45PM

Paper Session #1 - Abstracts

Theme: Psychosocial/Pain

Abstract Title: Mirror Therapy is Effective for Treating Upper Extremity Phantom Pain

Authors: Sacha Finn, Briana Perry, Jay Clasing, Lisa Walters, Sandra Jarzombek, Sean Curran, Minoo Rouhanian, Paul Pasquina and Jack Tsao

Abstract: Objective: Phantom limb pain is prevalent in patients post-amputation and is difficult to treat. We assessed the efficacy of mirror therapy in relieving phantom limb pain in unilateral, upper extremity (UE) amputees.

Methods: Fifteen participants from Walter Reed and Brooke Army Medical Centers were randomly assigned to one of two groups: mirror therapy (n=9) or control (n=6, covered mirror or mental visualization therapy). Participants were asked to perform 15 minutes of their assigned therapy daily for four weeks. The primary outcome was pain as measured using a 100-mm Visual Analogue Scale (VAS).

Results: Subjects in the mirror therapy group had a significant decrease in pain scores, from a mean of 44.1 (SD=17.0) to 27.5 (SD=17.2) mm (p=0.002). In addition, there was a significant decrease in daily time experiencing pain, from a mean of 1022 (SD=673) to 448 (SD=565) minutes (p=0.003). In contrast, the control group had neither diminished pain (p=0.65) nor decreased overall time experiencing pain (p=0.49). A response seen by the tenth treatment session was predictive of final efficacy.

Conclusions: These results confirm that mirror therapy is an effective therapy for phantom limb pain in unilateral, upper extremity amputees, reducing both severity and duration of daily episodes.

Theme: Psychosocial/Pain

Abstract Title: The Influence of Targeted Muscle Reinnervation on Phantom Limb Pain

Authors: Agnes Sturma, Laura Hruby, Martin Diers, Herta Flor, Tanja Stamm, Cosima Prahm, Johannes Mayer and Oskar Aszmann

Abstract: Introduction: With an incidence of 50-80% Phantom Limb Pain (PLP) is a big challenge in amputation rehabilitation. Pain medication, psychosocial interventions and novel therapies such as mirror therapy, graded motor imagery, exergames and others were shown to be beneficial in small studies. Another current treatment strategy might be Targeted Muscle Reinnervation (TMR). It has already been shown that TMR can prevent neuroma pain. Additionally, increased intensity levels of PLP in amputees have been associated with cortical remapping in certain brain areas. Here, fMRI studies could show that TMR alters cortical reorganization processes subsequent to amputation. Therefore, it might also decrease the PLP associated with it.

Methods: To investigate the influence of TMR on PLP a cohort study with two intervention groups and one control group was conducted. While the first intervention group only had a TMR surgery, the second intervention group also received post-surgical rehabilitation and a prosthetic fitting controlled by the re-innervated muscles. Pain levels were assessed before surgical intervention and every 6 months after. Patients were included if they reported mean pain levels of VAS 3 and above, had no nerve injuries and no psychiatric conditions. The study was approved by our Ethics Review Board.

Results: At the current time 7 patients were assigned to the different study groups and have at least completed the one-year-follow-up: 2 patients are in control group, 3 in the first intervention group and 4 in the second intervention group. While the control group reported higher pain levels over time (mean VAS 4.3 in the beginning vs. 5.8 at one-year follow-up), the pain levels of the first intervention group improved from 6.8 to 5 and the pain levels in the second intervention group changed from 5.1 at baseline to 4.0 when using the prosthesis for six months.

Discussion: The results of this study support the previous findings and anecdotal reports that TMR has the potential to relief PLP. As the number of subjects who already completed the study is small, it is not possible to come to any conclusions whether rehabilitation and prosthetic fitting after TMR are reasonable measures to improve this effect. A larger sample size will also allow statistical calculations.

Theme: Psychosocial/Pain

Abstract Title: New evidence-based recommendations for pharmacologic treatment of phantom pain

Authors: Kristin Østlie

Abstract: Norway's first guideline for rehabilitation after acquired upper-limb loss was published online 30 March 2016, in the open-access electronic guideline platform MAGICapp. The guideline covers all aspects of post-amputation rehabilitation, including the treatment of phantom pain. The authors were a multidisciplinary work-group, led by MD PhD Kristin Østlie. Making the guideline, we followed the steps in the AGREE-II tool. Also, we used GRADE for systematic assessment of the quality of the evidence, and for grading the strength of the recommendations (weak or strong).

The guideline has 24 recommendations for pharmacologic treatment of phantom pain after the acute postoperative phase. Several of the recommendations are weak, partly due to indirect evidence (e.g. studies on other types of neuropathic pain). This however means that the recommendations are valid for treatment of phantom pain in both upper- and lower limb amputees. The recommendations to some extent follow existing national and international guidelines for the treatment of neuropathic pain, but for some drugs, the evidence specific to phantom pain necessitated adjustment of these recommendations. Our main recommendations for phantom pain are summarized below.

We suggest that paracetamol and NSAIDs are tried before other pharmacologic agents. We then suggest the SNRI duloxetine before gabapentin, and pregabalin if these medications do not give sufficient pain relief. The evidence for the effect of duloxetine on phantom pain is of the same quality as for gabapentin and pregabalin. Duloxetine however has the advantage of not needing a time-consuming gradually dose increase, and also, the evidence suggests that the side effects for the most common (60 mg) dose are on the placebo level. Furthermore, in Norway, gabapentin must have been tried to get financial reimbursement for the use of pregabalin. The next pharmacologic agents suggested are topical lidocaine and topical capsaicin.

For peroral morphine, transdermal buprenorphine, the TCA amitriptyline and tramadol, the evidence is less convincing for phantom pain than for other neuropathic pain, and side effects are common. These are therefore not suggested as first line drugs.

For IV morphine, botulinum toxin injections, SSRI, beta blockers, memantine, ketamine, muscle relaxants (e.g. Baclofen), calcitonin, tapentadol, transdermal fentanyl, fentanyl nasal spray and local injections of corticosteroids, sufficient evidence for effect on phantom pain is lacking, and we therefore recommend against the use of these agents for phantom pain.

Reference

Evidence-based guideline for rehabilitation after acquired upper limb loss in Norway [Norwegian] Østlie K (editor) et al. MAGICapp 30.03.16. www.magicapp.org/public/guideline/Jn3zaL

Theme: Sensory Feedback

Abstract Title: Embodiment of bi-directionally integrated prosthetic limbs

Authors: Courtney Shell, Rafael Granja-Vazquez, Zachary Thumser, Dylan Beckler and Paul Marasco

Abstract: The sense that a prosthetic hand is something other than the body, that it is a tool, prevents instinctive engagement with the device by amputees. We have built myoelectrically-controlled, battery-powered prosthetic limb systems with robotic sensation for home use that provide tactile feedback when the prosthetic fingers contact objects. These systems are currently employed in a take-home trial with amputee participants that have a biological neural machine interface (targeted reinnervation). We identified locations on the reinnervated skin of three participants that correspond to a feeling of touch on their missing fingers and matched them to sensors integrated with the terminal device digits (strain gages in D1-D3 and force sensitive resistors on D4 and D5). When sensors on the prosthesis detect contact, touch robots mounted above these locations press on the reinnervated skin to generate a feeling of proportional pressure that is projected to the appropriate missing fingertip. During baseline testing at the start of the ten month study period, we investigated whether tactile feedback during a series of psychophysical tests would induce a sense of ownership (i.e., embodiment) of the robotic prosthetic hand. Subjects completed questionnaires indicating the degree to which they agreed with nine different statements (three embodiment-related and six control). Two users showed greater embodiment of the prosthetic hand when tactile feedback was provided. The third user showed a slight trend toward embodiment when using his prosthesis both with and without tactile feedback provided by the touch robots. Providing a sense of touch to prosthesis users through a bi-directionally integrated limb encourages embodiment of the prosthetic hand so that it is interpreted as being part of the amputee's body.

Theme: Sensory Feedback

Abstract Title: Myoelectric Prosthesis Control: Does Augmented Feedback Improve Internal Model Strength and Performance?

Authors: Ahmed Shehata, Erik Scheme and Jonathon Sensinger

Abstract: Amputees lack some of the sensory information that able-bodied persons incorporate in the use of their limbs; as a result, the control of myoelectric powered prostheses requires constant visual attention and a high level of concentration, which may lead to poor performance. Recent advances in signal processing and sensory technology have enabled the development of various methods of sensory feedback, including auditory, vibrotactile and electrotactile, which may be used to augment the feedback provided to prosthesis users. Researchers have explored the advantages of this augmented feedback by looking at the short-term performance results, but have not explored its effect on the development of the user's internal model, which affects the long-term performance. In this work, we investigate the notion that some controllers provide better short-term performance at the expense of providing inadequate feedback to develop a strong internal model, whereas other controllers may provide adequate feedback, but at the expense of more noisy control signals. We hypothesize that augmented feedback may be used to mitigate this tradeoff, ultimately improving short and long-term control. Using psychophysical assessment tools, we measured the internal models developed for three myoelectric controllers: 1) raw control with raw feedback (RCRF), such as a regression, 2) filtered control with filtered feedback (FCFF), such as a classifier, and 3) filtered control with audio augmented feedback (FCAF), such as a classifier control with augmented regression feedback. We assessed the short-term performance of these three control interfaces using a multi degree-of-freedom constrained-time target acquisition task. Results obtained from 30 able-bodied subjects showed that the FCAF control strategy enabled the development of a stronger internal model than FCFF, better accuracy and path efficiency than RCRF. These results support our hypothesis that the use of augmented feedback control strategies may improve both short-term and long-term performance.

Theme: Sensory Feedback

Abstract Title: Neural interface technology to restore natural sensation in lower-limb amputees

Authors: Hamid Charkhkar, Courtney Shell, Paul Marasco, Dustin Tyler and Ronald Triolo

Abstract: Sensory input in lower limb amputees is critically important to maintaining balance, preventing falls, negotiating uneven terrain, responding to unexpected perturbations, and developing the confidence required for societal participation and public interactions in unfamiliar environments. Despite noteworthy advances in robotic prostheses for lower limb amputees, such as microprocessor knees and powered ankles, natural somatosensory feedback from the lost limb has not yet been incorporated in current prosthetic technologies. To compensate for this lack of sensation, amputees rely on visual monitoring of their prosthetic limbs, and often increase loads applied to their intact limbs during standing and walking, putting them at risk for long term damage. Although there have been numerous attempts to provide sensory feedback via tactile or electro-cutaneous sensory substitution, nothing to date has successfully restored natural sensation that is perceived immediately and directly as coming from the missing limb. In this work, we report eliciting somatic sensation with neural stimulation in two transtibial amputees. The participants received high-density, flexible, 16-contact nerve cuff electrodes for the selective activation of sensory fascicles in the nerves of the posterior thigh above the knee. In the first subject the cuff electrodes were implanted on the sciatic nerve just above, and the tibial fibular nerves just below the bifurcation. The second subject had two cuff electrodes implanted 3cm apart on the sciatic nerve and one on the tibial nerve. Multiple cuff electrodes were deployed to maximize spatial resolution and increase the likelihood of isolating the desired sensory axons, as well as to explore the degree of selectivity and overlap in responses produced from distal and proximal locations on the nerves. Electrical pulses at safe levels were delivered to the nerves by an external stimulator via percutaneous leads attached to the cuff electrodes. The neural stimulation was perceived by participants in the study as sensation originating from the missing limb. We quantitatively and qualitatively ascertained the quality, intensity, and modality (pressure, touch, and proprioception) as well as the location of the perceived sensation. Stimulation through individual contacts within the nerve cuffs evoked sensations of various modalities and at discrete locations referred to the missing toes, foot and ankle, as well as in the residual limb. About 60% of 48 contacts in the cuffs produced perceptions 3 months post-implant in response to electrical stimulation. Based on our findings, the high density cuff technology is suitable in restoring natural sensation to lower limb amputees.

Theme: Sensory Feedback

Abstract Title: Providing High-resolution Tactile and Proprioceptive Somatosensory Feedback in Humans After Long-term Amputation of the Hand

Authors: Jacob A. George, David T. Kluger, David M. Page, Suzanne M. Wendelken, Tyler S. Davis, Christopher Duncan, Douglas T. Hutchinson and Gregory A. Clark

Abstract: The long-term goal of these studies is to provide rich, biofidelic tactile and proprioceptive feedback from an advanced prosthetic hand after prior amputation in humans. Six human subjects (S1-S6) received one or two 100-electrode Utah Slanted Electrode Arrays (USEAs; Blackrock Microsystems) implanted chronically (1-9 months) in residual median and/or ulnar nerves for stimulating sensory fibers (and recording from motor fibers) after long-term (2- to 25-y) transradial amputations. Sensory percepts were mapped by passing increasing current through individual USEA electrodes (biphasic, 200-μs pulses; 100-200 Hz, 200-500 ms trains) until the subject reported a percept (location, type, and intensity), or until stimulation maximum (< 100 μA). Experiments were conducted either in a MuJoCo (Roboti, LLC) virtual reality environment (VRE); or with a simple sensorized, motorized physical prosthetic hand (Open Bionics); or with a more advanced, motorized and sensorized prosthetic hand (DEKA) having 6 DOFs and 19 receptive fields. Subjects reported up to 131 different USEA-evoked cutaneous (e.g., pressure, vibration) or proprioceptive percepts (e.g., joint movement, muscle force). Typically, the evoked percepts covered most of the phantom hand, corresponded to normal afferent fiber distributions, and were enjoyed by subjects. Most percepts showed within-session stability, and in S6 more than half maintained location stability when retested at > 1 month. Subjects successfully discriminated among percepts having different phantom spatial locations or qualities, evoked by individual electrodes or combinations of electrodes. Recent subjects also used sensory feedback evoked by biofidelic afferent fiber stimulation to guide motor control in the VRE. Reciprocally, active engagement with the VRE influenced subjects' perceptions. S6 could discriminate between "soft" foam blocks and "hard" plastic blocks in a sensorimotor task using the DEKA hand (15 successes in 18 trials). S6 also showed objective evidence of embodiment of the simple sensorized, motorized prosthetic hand (as measured by proprioceptive shift from the amputated hand to the prosthetic hand and by responses to survey questions). Stimulation of sensory fibers also resulted in a 23.2% reduction in subjective phantom pain scores for S6 (from 3.75 ± .14 to 2.88 ± .18, $p < 0.005$). Such effects may enhance adoption of advanced hand prostheses by end-users. These results document an unprecedented level of high-resolution tactile and proprioceptive somatosensory percepts in humans with prior hand amputation. The emerging ability to provide a relatively complex repertoire of somatosensory inputs may enhance sensorimotor control, a sense of embodiment, and phantom pain reduction for users of advanced neuroprosthetic limbs.

Paper Session #2 – Abstracts

Theme: Upper Limb Prosthesis Device Design

Abstract Title: A study investigating targeted muscle reinnervation for individuals with transradial amputations

Authors: Todd Kuiken, Kristi Turner, Laura Miller and Annie Simon

Abstract: Current strategies do not allow individuals with a transradial amputation to fully benefit from newly available multi-articulating hand prostheses. Targeted Muscle Reinnervation (TMR) surgery, where residual nerves are transferred to target muscle sites, has been successful in providing additional neural control information for higher-level amputees [1]. Additionally, pattern recognition (PR) of residual limb muscle signals has provided advanced control of multifunction prostheses. The objectives of this study were to quantify and compare PR control of a multi-articulating hand before and after TMR surgery in transradial amputees.

Previous myoelectric users with a unilateral transradial amputation were recruited and enrolled at the Shirley Ryan AbilityLab and Walter Reed National Military Medical Center. Subjects were fit with a custom socket with eight bipolar electromyography (EMG) channels, a passive wrist, modified Touch Bionics i-limb revolution hand, and a Coapt Complete Control System. The study was divided into three 8-week home trials: pre-TMR conventional control, pre-TMR PR control, and post-TMR PR control. Subjects participated in the pre-TMR home trials in a randomized order. For the TMR surgery, the median nerve was transferred to the flexor digitorum superficialis muscle and the ulnar nerve to the flexor carpi ulnaris muscle. Subjects participated in the post-TMR home trial at least 6 months post surgery. Prior to starting each home trial, subjects were trained with an Occupational Therapist. While at home, they complete a daily log of their wear time, usage, and level of control of the device. At the end of each home trial, a variety of outcome measures were scored including the Southampton Hand Assessment Procedure and the Assessment of Capacity for Myoelectric Control.

Currently, three subjects are participating in home trials. The grips were selected with the help of the occupational therapist to include those most functional for a variety of daily activities. With pre-TMR conventional control, all subjects were able to select up to five grips using four triggers. With pre-TMR PR control, the two subjects who have begun home trials have selected four grips (Tripod, key, power, and precision pinch open). While the subjects have had 3-5 grips available, mainly two grips were used. Current use times reported for the home trials averaged 4.5 hours/day for subject one and 2.2 hours/day for subject two. Post-TMR PR home trial results will be discussed as well as any differences seen in the level of prosthesis control and/or performance compared to the pre-TMR PR home trial.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Initial Clinical Evaluation of the Modular Prosthetic Limb System for Upper Extremity Amputees

Authors: Kristin Yu, Courtney Moran, Robert Armiger, Matthew Johannes, Paul Pasquina and Michelle Nordstrom

Abstract: **Background**: This study evaluates the performance and usability of the Modular Prosthetic Limb (MPL) in the clinical setting to assess usability and optimize its control and features.

The MPL provides intuitive control schemes to command up to 17 independent joints using real-time embedded software to replicate the functionality of a normal arm and hand, achieved with an array of sEMG sites for intuitive movement via pattern recognition.

Methods: This is a non-randomized clinical optimization study. Up to 24 upper extremity amputees will be enrolled, with the first 12 to achieve the minimal level of VIE-based pattern recognition control progressing to clinical use. Optimization is based on performance and usability in pattern recognition training and functional improvements with respect to the number of available, controllable degrees of freedom.

This study consists of a virtual training Phase 1 and integrated training-and-use Phase 2. During Phase 1, participants train in a miniature virtual integrated environment to learn pattern recognition.

During Phase 2, prosthetic sockets are integrated with sEMG electrodes to allow users to operate the MPL. Data is obtained during performance of activities of daily living and from standardized, validated self-report and functional assessments administered in clinical sessions.

Results: Seven participants across multiple levels of upper extremity amputation have completed the protocol to date. Participants were able to control a greater number of individual joint and hand motions and increase proficiency with these motions over time. All participants, except one, improved in average motion completion percentages and path efficiencies—normalized by the total number of motions tested—on a Target Achievement Test over time, independent of level or cause of amputation. While speed to complete tasks with the MPL did not approach the speed with a conventional prosthesis, participants utilized a greater number of motions than with their conventional prosthesis and the fidelity of MPL control continued to improve.

Conclusion: Participants demonstrated the ability to control a greater number of motions, utilize multiple task-appropriate grasps, and describe a more intuitive control experience than currently available with conventional prostheses. While quantitative functional assessment scores were lower than conventional, MPL use and pattern recognition control improved over time with respect to the number and quality of motions controlled without plateau, indicating further potential function gains.

Disclaimer: The views expressed are those of the authors and do not reflect the official views of the Department of the Army, the Department of Defense, or the U.S. government.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Biomimetic model-based hand control: progress and challenges for myoelectric prosthetics

Authors: Robert Gaunt, Sergiy Yakovenko, Valeriya Gritsenko, Lee Fisher, Misagh Mansouri Boroujeni, Carl Beringer, Anton Sobinov, Matthew Boots, Jennifer Collinger and Michael Boninger

Abstract: Commercial upper-limb prostheses are functionally constrained by the lack of suitable myoelectric control signals. Although dexterous prosthetic hands are becoming more available on the market, controlling these devices often requires non-intuitive methods, such as inertial measurement units placed on the feet, or more commonly, selection of a grasp pattern followed by actuation. These control methods have a key factor in common; they require non-intuitive signals to replicate what able-bodied people achieve effortlessly. More advanced approaches, typically based on pattern recognition algorithms, are being developed to provide more intuitive control. However, as we move towards simultaneous control of the wrist and individual fingers, even these approaches face challenges. Here, we propose an alternative method that leverages anatomical and physiological knowledge of muscle function and hand biomechanics to create a biomimetic musculoskeletal control system. This approach assumes that multi-channel, fully implanted myoelectric recording systems, currently under final evaluation and testing, will be available in the near future. Here, we describe the general framework for this biomimetic controller and highlight some of the progress, as well as challenges, in developing such a system.

All procedures were approved by the University of Pittsburgh Institutional Review Board and the US Army Human Research Protection Office. Nine able-bodied subjects and one transradial amputee were enrolled in the study. Intramuscular EMG data were recorded from 16 fine-wire electrodes placed in the extrinsic hand and wrist muscles under ultrasound guidance. EMG and kinematic data were collected during structured hand and wrist movements.

At present, we have implemented a system that enables real-time control of simulated or physical prosthetic hands. We use Hill-type muscle models (29 muscles) and forward dynamic stimulations in MuJoCo to convert muscle activations, estimated from EMG signals, to muscle force, then joint torque, and ultimately movement. For the 18 mechanical degrees-of-freedom (DOF) and 29 muscles, this can be achieved in less than 1 ms. These simulations are generally stable, although noise in EMG signals and limited modelling of muscle activation-contraction dynamics, may limit current performance. Simultaneous control of 3-4 DOF is routinely achieve, although maintaining static postures remains a challenge. We are currently comparing simulated kinematic outputs to ground truth kinematics from able-bodied subjects to identify and evaluate the impact of changing model parameters. We believe that this overall approach will eventually enable restoration of dexterous prosthetic hand movements by encapsulating the normal musculoskeletal dynamics within the model while limiting reliance on training data sets.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: High-resolution, Real-time Motor Control of Prosthetic Hands in Humans After Long-term Amputation

Authors: Gregory Clark, Suzanne Wendelken, Tyler Davis, David Kluger, David Page, Jacob George, Christopher Duncan and Douglas Hutchinson

Abstract: To explore the ability to use peripheral neural and myoelectric signals to control advanced prosthetic hands, six human subjects (S1-S6) received one or two 100-electrode Utah Slanted Electrode Arrays (USEAs; Blackrock Microsystems) implanted chronically (1-9 months) in residual median and/or ulnar nerves for recording from motor fibers and for stimulation of sensory fibers (George et al., MEC17) after long-term (2- to 25-y) transradial amputations. S5 and S6 also received a 32-electrode electromyogram (EMG) assembly implanted in residual forearm muscles (Ripple, LLC). Motor control was provided by real-time decodes of myoelectric and neural signals; myoelectric signals provided the dominant control in subjects with both implants. EMG power and neural firing rate provided the features used for Kalman-filter decode algorithms. During initial "training" sessions, subjects viewed individuated digit or wrist movements of a virtual hand and attempted to mimic these movements with their phantom hand. The neural and EMG activity associated with the imagined phantom movements was then used to select neural and EMG channels from among 720 single-ended or differential possibilities (Nieveen et al., MEC17), and to set the parameters of the Kalman filter. The Kalman filter output was used to control a virtual or physical prosthetic hand in subsequent "testing" sessions. Experiments were conducted either in a MuJoCo (Roboti, LLC) virtual reality environment; or with a simple sensorized, motorized physical prosthetic hand (Open Bionics); or with a more advanced, motorized and sensorized prosthetic hand (DEKA) having 6 DOFs and 19 receptive fields. Recent subjects successfully controlled up to nine real-time degrees-of-freedom (DOFs) involving 18 digit and wrist movements of a virtual hand in a formal target-touching test (e.g., 53 successes in 54 trials). One subject achieved up to 12 apparent DOFs in informal tests. Both proportional position and velocity control were achieved. Additionally, subjects successfully combined individual DOF movements into novel grasps (e.g., "pinch") that had not been explicitly trained. EMG decodes remained stable for over a week (e.g., 26 successes in 26 trials in a 3-DOF, 4-level novel virtual grasp-matching task). S6 controlled the digits and wrist of the DEKA physical hand in both trained and untrained movements and grasps. Subjects also successfully used USEA-evoked sensory feedback to guide their motor behaviors in real-time closed-loop control. These results document an unprecedented level of real-time proportional control of a prosthetic hand in humans with long-term hand amputation. Future research includes translating these approaches to a wireless, practical take-home system.

Theme: Clinical Prosthetics

Abstract Title: Clinical Fitting of Four Patients Using Myoelectric Prostheses and Gel Liners with Magnetic Coupling for Transmission of Electromyographic Signals

Authors: Robert Lipschutz

Abstract: Research and development had been undertaken regarding the utilization of gel liners in conjunction with myoelectric fittings. To date; four individuals with various limb presentations and prosthetic components have been fit clinically with prostheses that incorporate gel liners and magnetic couplings that are being used for the transmission of the electromyographic (EMG) signals. The levels of amputation for these individuals include: one long transhumeral, one elbow disarticulation, and two transradial limbs. Different surgical techniques and components have been used for each of these designs based on etiology of amputation, residual limb length and patient preference. Two of the limbs, the long transhumeral and one of the transradial, have undergone targeted muscle reinnervation (TMR), while the other two have not. Three of the prostheses have: electronic wrist rotators, multi-articulating hands, and pattern recognition hardware, but not necessarily in this combination. The common factor between all of these fittings revolves around the utilization of gel liners with the magnetic coupling design.

Theme: Clinical Prosthetics

Abstract Title: Utilizing Wrist Movement for Prehension in an Atypical Case of Bilateral Partial Hand Amputation

Authors: Phillip Stevens

Abstract: This case study presents upon the unique utilization of wrist movement for prehension in an atypical case of bilateral partial hand amputation. The patient in question presented with a single residual metacarpal on both extremities. These digits were sensate. Mobilization was limited to wrist flexion with limited extension range. Recognizing the value of these sensate digits and the remaining active motion of the distal extremities, a two-position APRL thumb was placed on the ventral aspect of the wrist to provide an opposition post to the residual digit. This approach was used bilaterally, permitting bilateral active prehension with a sensate digit.

This concept was further exploited in the fabrication of custom silicone restoration prostheses in which the individual digits mobilized the metacarpal region of the hands bilaterally while the silicone thumbs were stabilized against the ventral aspects of the forearms.

The prosthetic solutions enabled the patient to benefit from the residual sensation and mobility afforded by his unique presentation to produce bilateral active prehension.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: 3D-Gaze and Movement: a novel metric of visual attention to measure upper limb prosthetic function

Authors: Jacqueline Hebert, Ewen Lavoie, Quinn Boser, Aida Valevicius, Albert Vette, Patrick M. Pilarski and Craig Chapman

Abstract: A lack of sensory feedback is often highlighted as a limiting factor to the use of powered upper limb prosthetic devices. From a functional perspective, sensory feedback is hoped to reduce cognitive burden and lessen the need for visual attention to task. However, standardized methods to quantify visual attention are limited, and there is a large technological burden with certain methods. We developed a novel method of integrating eye and motion tracking during defined functional tasks, which allows identification of eye gaze behaviour in relation to object interaction for each segment of movement.

Twenty able-bodied participants with normal upper limb function and 10 prosthetic users participated in the study. They performed two functional upper limb tasks, a pasta box task and a cup transfer task, with synchronized upper limb motion capture and eye tracking data collection. Using the kinematic data, each movement was segmented into 4 movement phases: Reach, Grasp, Transport, and Release, and eye fixations were analyzed according to: current location being acted on by the hand ('Current'), the future location that the hand will act on when it has completed its current action ('Future'), and the hand itself when no other AOI is being fixated (Hand). The results of one transhumeral prosthetic user, using two different prosthetic devices compared to normative results, is presented.

The prosthetic user showed significantly slower movement times, spending a disproportionally longer time in the grasp phase compared to the other phases. With respect to eye behaviour, in the reach phase, the prosthetic user spent relatively more time fixated particularly on the myoelectric terminal device compared to the body powered condition, with both prosthetic conditions having a greater ratio of fixation time to hand than normative subjects. During transport of the object, the ratio of eye fixation to hand was dramatically increased in both prosthetic conditions compared to normative. This resulted in the prosthetic users spending relatively less time during transport fixating on the target to where they were moving the object (ie. reduced "look ahead" fixations).

This novel method of eye gaze behaviour analysis precisely quantified the visual attention demands of a prosthetic user during functional tasks. There were some interesting differences between myoelectric and body powered prosthetic performance that may have been due to proprioceptive feedback. Measuring changes in visual demand with new interventions may give insight into the relative importance of vision in accomplishing tasks for prosthetic users.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Measure of Pain Variables and Primary Prosthesis (Body vs Electric)

Authors: Tiffany Ryan, John Miguelez and Nathan Kerns

Abstract: BACKGROUND: Numbness and phantom limb pain(PLP) have been found to negatively impact the upper limb(UL) amputees' functional ability and/or participation in activity. Clinicians must evaluate and monitor the impact of any association between prosthesis use and physical discomfort. Secondary to clinical experiences indicating a differences in physical discomfort severity between body powered(BP) and electric users, objective clinical survey results of UL amputees' report of residual limb numbness and pain, PLP and level of wear are presented.

METHODS: Consenting subjects from a convenience sample from patients presenting in seven out-patient UL prosthetic rehabilitation specialty centers completed the Comprehensive Arm Prosthesis and Rehabilitation Outcome Questionnaire-Revised©, (CAPROQ-R©) at various prosthetic fitting phases of care. These subjects objectively ranked the physical and functional factors influencing prosthetic performance. Categories reviewed for this study include: residual limb numbness and pain, phantom limb pain(PLP) and prosthesis wear time. The consented final sample size, after excluding non-responses, was one hundred eighteen. Results of subjects' survey most distant from the initial fitting were evaluated for this study.

A series of paired-samples t-tests were conducted to assess change in self-reported numbness, residual limb pain, and PLP when the participant was wearing their prosthesis versus not wearing their prosthesis. Analyses were conducted separately for participant that nominated a BP prosthesis as their "primary prosthesis" ($n = 27$; Mage = 46.61; 85.2% male) and those who nominated an electrically-powered prosthesis as their primary prosthesis ($n = 64$; Mage = 59.12; 70.3% male).

RESULTS: Results of the analyses of BP users found no significant change in numbness ($p = .858$), residual limb pain ($p = .340$), or PLP ($p = .826$). Similarly, results of the analyses of electrically-powered users found no significant change in numbness ($p = .780$) or residual limb pain ($p = .294$). However, there was a significant change in electrically powered users' PLP ($p < .001$); more specifically, these participants reported significantly less PLP when wearing their prosthesis ($M = 3.86$, $SD = 2.96$) than when they were not wearing their prosthesis ($M = 5.41$, $SD = 2.44$).

CONCLUSION: Objective outcomes describing the impact of prosthesis control on factors known to limit an UL amputee's activity engagement have the potential to positively influence clinical protocols and industry research and development. Continued research to further evaluate the impact of the variances in electric prosthesis types and materials and methods of prosthesis-human integration and the potential positive impact on medical outcomes.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Upper Limb Myoelectric Prostheses: User and Therapist Perspectives on Quantifying Benefits of Pattern Recognition Control

Authors: Andreas Franzke, Raoul Bongers, Barbara Pobatschnig, Fabian Unglaube, Andreas Kranzl, Alessio Murgia and Corry van der Sluis

Abstract: Pattern Recognition (PR) might facilitate intuitive prosthesis control, which in return should facilitate the execution of activities of daily living (ADLs) for amputees. Tests to evaluate PR-based control and its implementation in daily use are currently not available but are required. These tests should ideally reflect realistic prosthesis utilization, and be based on ADLs that users of modern multi degree-of-freedom (DOF) prosthetic hands perceive as relevant or difficult to execute.

The aim of this study was therefore to describe control issues with current multi DOF prostheses and to identify pertinent ADLs from the perspective of patients and therapists.

We conducted semi-structured interviews with 16 adult patients and 7 therapists who were experienced with multi-DOF myoelectric prosthetic hands. Patient inclusion criteria were unilateral amputation at transradial or wrist level and at least six months of experience with the above mentioned prosthetic hands. Therapist inclusion criteria were at least six months of experience with the treatment of such patients. Moreover we included patients and therapists who already had experience with PR-based myoelectric prostheses. The interviews were recorded and transcribed by an independent person. Data was analysed according to a 5-step framework approach based on Familiarization, Creating a thematic framework, Indexing, Charting, and Mapping & Interpretation.

Myoelectric control was often described as too slow, fatiguing and requiring strong mental effort due to non-intuitive mode-switching signals. This also led to the selection of a small number of employed grip/movement modes. Relevant and difficult ADLs differed between individuals, but recurrent domains were mostly preparation of food, eating and dressing. Many patients perceived their multi-DOF prosthesis as a tool which should be able to support the sound hand in bimanual tasks, when these become very difficult or impossible to perform with one hand. Patients mainly choose a multi-DOF myoelectric hand because they expect additional functionality in comparison to conventional myoelectric prostheses, which may not always be experienced ultimately. Persisting problems were low technical robustness and poor manufacturer support (e.g. long waiting times for replacement of parts).

This study revealed several aspects worth considering when testing future (PR-based) myoelectric prostheses. The test should involve bimanual tasks related to preparing food, eating or dressing, where the prosthetic hand works to assist the sound hand. Next to completion time and quality of movement, variables such as ease of use, mental effort, embodiment and grip type variety might indicate whether PR holds benefits for the patient in myoelectric prosthesis control.

Day 2

Wednesday, August 16, 2017

Grand Ballroom – Delta Hotel

Day at-a-glance	
8:00AM-9:00AM	Buffet Breakfast
8:30AM-9:00AM	Vendor Workshop: Coapt
9:00AM-9:15AM	Housekeeping
9:15AM-10:15AM	Keynote Address: Jeff Tiessen
10:15AM-10:45AM	Nutrition Break / Vendor Displays
10:45AM-12:00PM	Paper Session #3
12:00PM-1:00PM	Lunch Break / Vendor Displays
1:00PM-2:45PM	Paper Session #4
2:45PM-3:45PM	Poster Session B: Fast-Track Presenters at Podium Nutrition Break / Vendor Displays
3:45PM-4:30PM	Paper Session #5
4:30PM-5:00PM	End of Day Comments

Paper Session #3 - 10:45AM-12:00PM

Themes	Paper title	ID	Presenting Author
Upper/Lower Limb Myoelectric Control	Pattern recognition control of the DEKA arm in two transhumeral amputees with targeted muscle reinnervation	45	Linda Resnik
	Online tactile myography for simultaneous and proportional hand and wrist myocontrol	94	Claudio Castellini
	Development of a wireless multichannel myoelectric implant for prosthesis control	135	Daniel McDonnall
	Multi-level combination of electromyogram and inertial measurments for improved myoelectric pattern recognition	83	Kianoush Nazarpour
Clinical Prosthetics	Layperson's 3-D Printed Post-Operative Prostheses Following Bilateral Wrist Disarticulation	76	Phillip Stevens
	A pediatric shoulder disarticulation/partial hand: Case study and six year follow-up	14	Jack Uellendahl

Paper Session #4 - 1:00PM-2:45PM

Themes	Paper title	ID	Presenting Author
Upper/Lower Limb Myoelectric Control	Myoelectric Elbow-Wrist-Hand Orthoses (MEWHO) used to restore function in a weak upper extremity resulting from chronic stroke - A case study report	134	Jonathan Naft
	Improving hand and wrist activity detection using tactile sensors and tensor regression methods on Riemannian manifolds	38	Claudio Castellini
	High Degree-of-Freedom Control of Virtual and Robotic Prosthetic Hands Using Surface EMG	93	Suzanne Wendelken
Upper Limb Prosthesis Device Design	A Comparison of Home Trials with Multiple Devices and Controls with a Single TH TMR Subject	104	Laura Miller
	Towards More Versatile Grasp: A New Body-Powered VO/VC Terminal Device	19	Bradley Veatch
	The TITAN Finger: A Heavy Duty Titanium finger option for Partial Hand patients	4	Matthew Mikosz
	The Point Digit: A passive, ratcheting prosthetic finger manufactured using metal laser sintering technology	41	Jacob Segil
	The SoftHand Pro-H: A prosthetic platform for work-oriented applications	116	Sasha Godfrey

Poster Session B: Fast-Track Presenters at Podium – See page 93 for listings and abstracts

Nutrition Break / Vendor Displays

2:45PM-3:45PM

Paper Session #5 - 3:45PM-4:30PM

	Paper title	ID	Presenting Author
Theme Occupational Therapy & Outcome Measures	Outcome measures improve following home use with pattern recognition control	22	Levi Hargrove
	Quantifying Muscle Control in Myoelectric Training Games	131	Aaron Tabor
	A novel approach to visualising upper limb activity in myoelectric prosthesis users	86	Alix Chadwell
	Environmental barriers to participation and facilitators for myoelectric prosthesis use – a comparison with users of other assistive technology	36	Cathrine Widehammar
	The Clinical Application of a Myoelectric Training Tool for Upper Limb Amputees	95	Glyn Murgatroyd
	Relation between capacity and performance in paediatric myoelectric prosthesis users	58	Liselotte Hermansson

Paper Session #3 – Abstracts

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Pattern recognition control of the DEKA arm in two transhumeral amputees with targeted muscle reinnervation

Authors: Linda Resnik, Jill Cancio, Christopher Fantini, Andrea Ikeda and Nicole Sasson

Abstract: Background: Recent utilization of EMG pattern recognition (PR) as a control input for the DEKA Arm shows promise for decreasing cognitive burden by eliminating the foot controls. Purpose: To report outcomes and experiences of two subjects with transhumeral (TH) amputation who had undergone targeted muscle reinnervation and were fit with, and trained to use, a DEKA Arm, with 5 degrees of freedom (DOF) controlled by EMG PR. Methods: This study had 2 portions: in-laboratory training (Part A) and home use (Part B). Quantitative outcomes and qualitative data were collected at baseline, end of Part A and end of Part B. Results: Both subjects controlled a 5 DOF DEKA Arm using EMG PR and were generally satisfied with this control method. Quantitative outcomes were mixed. Subjects provided feedback on the DEKA Arm. Conclusion: PR control for the DEKA Arm was feasible in persons with transhumeral amputation who have undergone TMR surgery given adequate training.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Online tactile myography for simultaneous and proportional hand and wrist myocontrol

Authors: Christian Nissler, Mathilde Connan, Markus Nowak and Claudio Castellini

Abstract: Tactile myography is a promising method for dexterous myocontrol. It stems from the idea of detecting muscle activity, and hence the desired actions to be performed by a prosthesis, via the muscle deformations induced by said activity, using a tactile sensor on the stump. Tactile sensing is high-resolution force / pressure sensing; such a technique promises to yield a rich flow of information about an amputated subject's intent.

In this work we propose a preliminary comparison between tactile myography and surface electromyography enforcing simultaneous and proportional control during an online target-reaching experiment. Six intact subjects and a trans-radial amputee were engaged in repeated hand opening, wrist flexion / extension and wrist pronation / supination, to various degrees of activation. Albeit limited, the results we show indicate that tactile myography enforces an almost uniformly better performance than sEMG.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Development of a wireless multichannel myoelectric implant for prosthesis control

Authors: Daniel McDonnall, Scott Hiatt, Brian Crofts, Christopher Smith and Daniel Merrill

Abstract: Complete functional adoption of upper limb prostheses is unacceptably low. Myoelectric device rejection rates are comparable to those of body-powered prostheses, even though these devices should be capable of providing better function. Amputees cite awkward use and lack of perceived utility of their myoelectric prostheses, as well as dissatisfaction with the ability to perform ADLs. Ultimately, poor control of myoelectric systems limits the adoption of advanced hand prostheses.

Prosthesis manufacturers have released substantially improved prosthetic arm technology in the last decade; however, a well-documented challenge with the implementation of current myoelectric devices is the common use of only two surface EMG electrodes for collection of control signals. Limitations in the control signals extracted from surface EMG signals prevent the implementation of advanced control algorithms and intuitive movement. As a result, these advanced prostheses still require serial selection and control of individual joints and grips resulting in slow, unnatural motions.

Ripple has developed an implantable system which simultaneously records 32 channels of myoelectric data from multiple residual muscles, and transmits these data to an external transceiver placed in the prosthetic socket. Our objective is to provide simultaneous multi-degree of freedom prosthesis control, ultimately providing an intuitive control experience. This approach supports a high number of independent control signals and provides access to EMG from deep muscles that cannot be accessed with surface electrodes.

The system comprises a hermetic implanted module from which nine EMG leads emerge. Eight of the leads contain four electrode sites each for 32 total recording channels. A ninth lead provides the reference electrode. The implant receives power inductively from an external transceiver and sends digitized EMG data to the external transceiver via infrared light. By using a single subcutaneous module for telemetry from which several leads emerge, power coupling efficiency remains high.

We have demonstrated high data rate transmission using infrared light in chronically implanted canine. Devices were implanted in deltoideous and the long and lateral heads of triceps. Recorded EMG demonstrate very low noise and clearly indicate antagonistic activity of the gait muscles. We have completed initial safety and performance testing.

These efforts demonstrate the ability to amplify and transmit muscle signals and confirm safety and performance requirements. This approach has the potential to provide simultaneous multi-degree of freedom prosthesis control, especially if used with dexterous prostheses, surgical reinnervation techniques (TMR and RPNI), and advanced algorithms.

This work was supported by NIH U44NS067784 and DARPA HR0011-15-C-0036.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Multi-level combination of electromyogram and inertial measurements for improved myoelectric pattern recognition

Authors: Rami Khushaba, Agamemnon Krasoulis and Kianoush Nazarpour

Abstract: Advanced pattern recognition-based myoelectric prosthetic hands are currently limited due to the inadequate real-time control performance and the lack of classification robustness. In one direction of research, the extraction of accurate and efficient descriptors of muscular activity has been a major focus for improved myoelectric control while another direction considers the electromyogram (EMG) signal inadequate for reliable control and suggests that the use of inertial measurement (IM) data is needed. We propose to address the current limitations by considering a combination of robust feature extraction methods and a fusion of EMG and IMs. Our feature extraction algorithm employs the orientation between a set of descriptors of muscular activities and a nonlinearly mapped version of it. It also shifts the voting step from the classifier to the feature extraction stage by fusing the EMG signal power spectrum characteristics derived from each analysis window with the descriptors of previous windows for robust activity recognition. The proposed idea can be summarized in the following three steps: 1) extract power spectrum moments from the current analysis window and its nonlinearly scaled version in time-domain through Fourier transform relations, 2) compute the orientation between the two sets of moments, and 3) apply data fusion on the resulting orientation features for the current and previous time windows and use the result as the final feature set. We collected and analysed a dataset comprising of 20 able-bodied and two amputee participants executing 40 movements. In our experiments, we firstly show that the well-known methods can only achieve an average of 25% classification error across all subjects with 150 ms windows, and by using our proposed features we achieved significant reductions in error rates of up to 16% across all subjects ($p < 0.001$). The inclusion of the IM data further significantly enhanced the results by shrinking the classification error rates to an average of < 5% across all subjects ($p < 0.001$). We consider that the implications of our study could help improve the usability of upper-extremity prostheses in real-life applications.

Theme: Clinical Prosthetics

Abstract Title: Layperson's 3-D Printed Post-Operative Prostheses Following Bilateral Wrist Disarticulation

Authors: Keaton Valentine, Trevor Valentine and Phil Stevens

Abstract: This paper presents novel 3-D printed, post-operative prostheses created by the brother of a patient who had undergone bilateral wrist disarticulation amputations to span the time period between amputation and the fitting of preparatory prostheses. Following severe frost bite, attempted limb salvage and eventual amputation, the patient had been without upper limb prehensile function for 5 weeks at the time of his initial prosthetic consult. Following removal of surgical sutures, as the limbs continued to heal and volume reduction efforts were implemented, the patient's brother devised and manufactured post-operative prostheses to restore a degree of prehensile function over the next several weeks until the patient was fitted with preparatory body powered devices. The combination of 3-D printed and commercially available elements enabled the patient to hold and preposition utensils and paper work. In a separate configuration, he could hold a smart phone with one limb while using a stylus attached to the contralateral limb to navigate the phone screen. Elements of these designs will be described. The role of 3-D printing in the addressing the light duty, short term, immediate needs of post-operative prostheses may warrant further consideration and development.

Theme: Clinical Prosthetics

Abstract Title: A pediatric shoulder disarticulation/partial hand: Case study and six year follow-up

Authors: Jack Uellendahl

Abstract: Management of high level pediatric limb deficiency is challenging. Issues of prosthesis weight, complexity of control and functional utility are often cited as reasons for prosthesis rejection. Design goals include lightweight construction, simple control, and functional grasp [1]. This case study will review the prosthetic treatment over a six year period of an individual who presents with multiple congenital physical anomalies. Our subject, MK, presents with absence of his right arm at the shoulder disarticulation level, left partial hand with complete absence of his thumb, fused left elbow at sixty degrees of flexion, no forearm rotation, and scoliosis. This case presentation demonstrates that in cases where the prosthesis can provide functional gain, is light-weight and simple to control, the high level congenital limb deficient individual can achieve long-term success with appropriately designed prostheses.

Paper Session #4 - Abstracts

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Myoelectric Elbow-Wrist-Hand Orthoses (MEWHO) used to restore function in a weak upper extremity resulting from chronic stroke - A case study report

Authors: Jonathan Naft

Abstract: Every year in the U.S. approximately 795,000 people, (civilians, active military and veterans) experience a stroke . 40% of that group exhibit chronic disability including upper extremity (UE) impairments such as paresis and spasticity. Additionally, within the military, 33,149 U.S. personnel were diagnosed with a TBI in 2011 alone . For those survivors who undergo traditional rehabilitative therapies, they may frequently be left with chronic upper extremity impairments and an associated loss of function, dependence on caregivers and decreased quality of life. Custom fabricated myoelectric orthoses may provide an alternative solution to improve function and an adjunct to traditional therapies for those with hemiparesis and loss of UE function. It is the aim of this case report to describe the experience and assistive and rehabilitative outcomes of a veteran with one such custom myoelectric orthosis.

The myoelectric brace used for this case study is called the MyoPro. The Myopro® (Myomo Inc. Cambridge MA) is a custom fabricated myoelectric elbow-wrist-hand orthosis (EWHO) currently on the market for civilians as well as numerous VA facilities across the United States. Surface sensors - built into the orthosis and located over the upper arm and forearm muscles - detect the user's electromyographic (EMG) signal once he/she initiates a muscle contraction. The EMG signal activates the motors on the orthosis to move the elbow or hand in the desired direction, proportional to muscle output. (Figure 1.)

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Improving hand and wrist activity detection using tactile sensors and tensor regression methods on Riemannian manifolds

Authors: Noemie Jaquier, Claudio Castellini and Sylvain Calinon

Abstract: Simultaneous and proportional control of a prosthetic hand and wrist is still a controversial issue, although giant steps have lately been made in this direction.

In this paper, we study the application of a novel machine learning method to the problem, with the aim to potentially improve such control. Namely we apply different kernels for tensor Gaussian process regression to data obtained from an advanced, flexible tactile sensor applied on the skin, recording muscle bulging in the forearm. The sensor is a modular, compact bracelet comprising 320 highly sensitive elements organized as a tactile array.

The usage of kernel functions with tensor arguments and kernel distances computed on Riemannian manifolds enables us to account for the underlying structure and geometry of the tactile data. Regression accuracy results obtained on data previously collected using the bracelet demonstrate the effectiveness of the approach, especially when using Euclidean distance and Kullback-Leibler divergence-based kernels.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: High Degree-of-Freedom Control of Virtual and Robotic Prosthetic Hands Using Surface EMG

Authors: Suzanne Wendelken, Tyler Davis, Christopher Duncan, Jacob Nieveen, David Kluger, David Page, Jake George, Douglas Hutchinson, David Warren and Gregory Clark

Abstract: Dexterous, intuitive, multi degree-of-freedom (DOF) control of a prosthetic hand is a highly sought after feature for next-generation multi-articulated robotic prosthetic hands. Here we present results of ongoing studies in which transradial amputees and intact subjects instrumented with 14-to-22-electrode surface EMG (sEMG) assemblies were able to simultaneously control 6-to-8-DOF of a virtual or robotic hand, and generate novel grasps that were not previously trained.

Subjects were instrumented with up to 22 "wet" sEMG electrodes (Coviden, Mansfield, MA), or a sleeve containing ≥ 14 dry "button" electrodes (Motion Control, Salt Lake City, Utah) placed on the forearm or residual forearm clustered above digit and wrist muscles. Decode calibration data was collected at 1kHz using a bioamplifier (Ripple LLC, Salt Lake City, Utah) while the subjects followed repeated single-DOF movements of a virtual hand (e.g., index finger flexion) and one full-hand grasp movement. Data were filtered with a 15-375Hz bandpass filter. Amplitude of single-ended and software-differenced channel pairs were computed, binned in 33 ms windows, and used as the input to a Kalman filter decode algorithm, capable of position or velocity decoding modes. To further minimize crosstalk between DOFs, experimenter-selected gains and thresholds were applied to the outputs, which were then used to control in real-time a virtual hand in a virtual environment (MuJoCo), or a 6-DOF robotic prosthetic hand (DEKA, Manchester, NH). Individual DOF control was verified by means of a virtual target-touching task, where subjects were instructed to touch and hold single or multiple-DOF targets while holding the non-target DOFs in a neutral position. Multi-DOF, untrained movements and grasp and positions were further evaluated using the robotic or virtual hand during functional tests such as utensil holding and cup pouring.

A transradial amputee, using a 22-wet-electrode sEMG assembly, achieved 8-DOF control in a target-touching task (45/48 successful trials), similar to his performance using an implanted 32-electrode EMG assembly (47/48 successes). An intact subject was capable of 6-DOF control in a target-touching task using a 14-dry-electrode sEMG sleeve (30/30 successes). Subjects were also able to demonstrate the ability to make novel grasps (such as thumb-index pinch) in the virtual environment.

These studies show that simultaneous high-DOF control of a prosthetic hand using sEMG is possible and similar in performance to iEMG assemblies within sessions, although long-term stability has not yet been demonstrated. Our decoding strategies represent a novel and effective alternative to the commonly used "direct control" or nominal classifier strategies.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: A Comparison Of Home Trials With Multiple Devices And Controls With A Single TH TMR Subject

Authors: Todd Kuiken, Laura Miller, Levi Hargrove, Kristi Turner and Jon Sensinger

Abstract: Outcomes can be influenced by both componentry and by the type of control. A case is presented in which one subject completed minimum 6 week home trials with 4 different configurations: commercial arm system with a powered hook with direct control (DC), commercial arm system with a powered hook with pattern recognition (PR) control, a lab developed prosthesis with a powered hand with pattern recognition control and a lab developed prosthesis with a powered hook with pattern recognition control.

[1] J. B. Hijjawi, T. A. Kuiken, R. D. Lipschutz, L. A. Miller, K. A. Stubblefield, and G. A. Dumanian, "Improved myoelectric prosthesis control accomplished using multiple nerve transfers," Plastic and Reconstructive Surgery, vol. 118, pp. 1573-1578, DEC 2006.

[2] T. A. Kuiken, D. S. Childress, and W. Z. Rymer, "The Hyper-Reinnervation of Rat Skeletal-Muscle," Brain Research, vol. 676, pp. 113-123, APR 3 1995.

[3] L. A. Miller, K. A. Stubblefield, R. D. Lipschutz, B. A. Lock, and T. A. Kuiken, "Improved Myoelectric Prosthesis Control Using Targeted Reinnervation Surgery: A Case Series," Neural Systems and Rehabilitation Engineering, IEEE Transactions on [see also IEEE Trans. on Rehabilitation Engineering], vol. 16, pp. 46-50, 2008.

[4] T. A. Kuiken, et al., "Targeted Muscle Reinnervation for Real-time Myoelectric Control of Multifunction Artificial Arms," JAMA, vol. 301, pp. 619-628, February 11, 2009 2009.

[5] V. Mathiowetz, G. Volland, N. Kashman, and K. Weber, "Adult norms for the box and blocks test of manual dexterity," American Journal of Occupational Therapy vol. 39, pp. 386-391, 1985.

[6] R. H. Jebsen, N. Taylor, R. B. Trieschmann, M. J. Trotter, and L. A. Howard, "An objective and standardized test of hand function," Arch Phys Med Rehabil, vol. 50, pp. 311-9, Jun 1969.

[7] C. M. Light, P. H. Chappell, and P. J. Kyberd, "Establishing a standardized clinical assessment tool of pathologic and prosthetic hand function: normative data, reliability, and validity," Arch Phys Med Rehabil, vol. 83, pp. 776-83, Jun 2002.

[8] L. M. Hermansson, A. G. Fisher, B. Bernspang, and A. C. Eliasson, "Assessment of capacity for myoelectric control: a new Rasch-built measure of prosthetic hand control," J Rehabil Med, vol. 37, pp. 166-71, May 2005.

[9] R. D. Lipschutz, T. A. Kuiken, L. A. Miller, G. A. Dumanian, and K. A. Stubblefield, "Shoulder Disarticulation Externally Powered Prosthetic Fitting Following Targeted Muscle Reinnervation for Improved Myoelectric Control," Journal of Prosthetics and Orthotics, vol. 18, pp. 28-34, April 2006.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Towards More Versatile Grasp: A New Body-Powered VO/VC Terminal Device

Authors: Bradley Veatch

Abstract: Terminal devices (TDs) for body-powered (BP) upper-limb prostheses typically operate using either voluntary opening (VO) or voluntary closing (VC) grasping modes. Individuals familiar with TD design recognize that under certain conditions one mode performs better than the other, and that ideally, users would be free to select—with minimal thought and disruption—the one they felt most appropriate for a given task. ToughWare Prosthetics' patented new VO/VC TD gives users this choice; the core grasping technology is purposefully robust and mechanically simple, comprising an elastic bungee-type cord, spatial lever, and contoured grasping elements. With the lever in one position, the elastic cord doubles on itself, producing a strong (additive) force used to achieve VO grasp. A second lever position causes the band to operate differentially, providing a reduced force for biasing the unit open during VC grasp. The mechanism exploits geometric symmetry between these two lever positions and the forearm cable attachment point to ensure the user's harness and cable remain correctly adjusted for optimal operation between VO and VC. Switching is accomplished by moving the spatial lever between positions; cable excursion is identical for both modes at 2-1/4 inches. Early field testing revealed that grasping contours optimized for VO operation were comparatively poor for VC, and vice-versa. In response, new contours were developed maximizing hook utility and grasping zone visual acuity for VO, and implementing a novel tilted-axis concept that optimizes grasp stability under high loads for VC that simultaneously minimizes hook interference. Replaceable compliant friction pads located on the hook faces and medial palm further enhance overall grasp quality. Designed for manufacturability, the new TD embraces state-of-the-art additive manufacturing processes in both plastic and metal to reduce cost and weight (9 ounces) while achieving an elegant, aesthetically pleasing design that is just 4-5/8 inches long. This versatile grasping technology is part of an ongoing pilot program exploring how new amputees equipped with on-demand VO and VC grasp capability employ those modes to become proficient in their use with the objective of deriving maximum benefit and enjoyment of their BP prosthetic appliances.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: The TITAN Finger: A Heavy Duty Titanium finger option for Partial Hand patients

Authors: Matthew Mikosz

Abstract: This presentation will describe a new advancement in partial Hand technology. The design is a ratchet style heavy duty titanium finger called the TITAN finger that is modular and can be suitable for someone missing a full finger, partial finger or full thumb. The design operates by the user applying pressure to the dorsal side of the finger to allow the finger to ratchet into flexion. A steel pin engages into a gear that locks the finger in place. To extend the finger the user would dislocate the joint and position into a new extended position. There have been 70 devices fit in the US currently with many users who are utilizing the device for heavy duty activities and the feedback has been very positive to date. The TITAN finger has been in development for over a year and was released in mid 2016. Functional prototypes were designed and tested using a Form 2 SLA machine. The preferred method for fitting a TITAN full finger, TITAN Partial or TITAN Thumb would be to design a custom molded silicone interface and pre preg carbon fiber frame. This design offers many benefits which includes improved comfort, range of motion and durability compared to other materials. This design also allows for a very streamline socket with added strength and stability for heavy duty activities. Over the years there has been significant advancements in Partial Hand technology and the TITAN Finger can offer an additional option for someone seeking a device for heavy duty activities.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: The Point Digit: A passive, ratcheting prosthetic finger manufactured using metal laser sintering technology

Authors: Jacob Segil, Stephen Huddle, Levin Sliker and Richard Weir

Abstract: Partial hand amputees represent the largest population of individuals with upper-limb amputation. However, commercially available prosthetic finger devices lack strength, durability, and anatomically correct centers of rotation. We developed a passive, ratcheting prosthetic finger that is manufactured using metal laser sintering rapid manufacturing technology, the Point Digit.

The Point Digit is a purely mechanical prosthetic finger (i.e., no actuation, electronics, etc.). A ratchet positions the finger into one of ten distinct levels of flexion. The ratchet ensures that the finger is non-backdrivable and can withstand 250 lbs. (1.1 kN) of static load without failure. An EOS M270 direct metal laser sintering 3D printer manufactures most components of the Point Digit using maraging steel powder (EOS MaragingSteel MS1). This material has a yield strength of 152 ksi and modulus of elasticity of 23 Msi ensuring ample mechanical strength. An internal honeycomb structure maintains strength and reduces weight of the individual components. The average finger mass for all lengths of the Point Digit is 45g fully assembled. The length of the Point Digit can be scaled between 80 mm to 100 mm in length, which nearly encompasses the ranges of finger lengths for 25 – 75th percentile males and 50-100th percentile females.

The extension of the Point Digit can occur in two ways: 1) a self-locking button releases the ratchet and extends the finger or 2) the full flexion of the finger causes the finger to spring-back to full extension. By allowing external features to position the finger in both flexion and extension, the contralateral limb is not required for use of the Point Digit.

A kinematic linkage system couples all three joints of the Point Digit. This linkage system flexes all three joints at an anatomically appropriate rate. The linkage system ensures a finger that behaves similar to the intact limb while maintaining mechanical strength.

Finally, the Point Digit provides an anatomically appropriate center of rotation of the metacarpophalangeal joint. This feature ensures a clinically sound system that easily integrates into a prosthetic socket. A mounting bracket provides a method for prosthetists to install the Point Digit into the prosthetic socket and ensure appropriate positioning of the finger with respect to the physiological limb.

The Point Digit advances the field of prosthetic finger design by providing a durable, ratcheting prosthetic finger using metal laser sintering technology.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: The SoftHand Pro-H: A prosthetic platform for work-oriented applications

Authors: Sasha Godfrey, Cristina Piazza, Manuel G. Catalano, Matteo Rossi, Matteo Bianchi, Giorgio Grioli and Antonio Bicchi

Abstract: Body-powered prostheses are typically favored for heavy-duty use and employed in hostile environments, such as farm or factory work. With adequate training and practice, individuals with limb loss can become proficient in the usage of body-powered hooks (BPH) to accomplish a wide variety of tasks. Despite this versatility, there are drawbacks to this type of technology [1]. In this work, we present a novel prosthetic platform to address three of the most common issues in the use of BPH: 1. The need to frequently change terminal devices to task-specific solutions. 2. The loading of the shoulder due to the use of the figure-of-nine harness (the typical control system of body-powered prosthetic systems for users with unilateral limb loss). 3. The lack of functional, anthropomorphic solutions for users who prefer body-powered prosthetic solutions.

In contrast, myoelectric prostheses (MPs) are externally powered and controlled by muscle activity in the residual limb. Further, unlike the body-powered devices described above, they are typically anthropomorphic but more fragile, costly, and heavy. The most advanced versions offer multiple grasp postures, but are more difficult to control. Indeed, controlling even single degree of freedom (DOF) MPs can be challenging for some individuals, either because of their physiology or because of environmental factors [2].

The Pisa/IIT SoftHand [3] is a 19 DOF anthropomorphic robotic hand that combines intuitiveness, adaptivity and robustness. The mechanical design is based on studies on human kinematic synergies and leverages underactuation to simplify control and imparts adaptability to the grasp pattern. A previous prosthetic implementation of the Pisa/IIT SoftHand, the myoelectrically-controlled SoftHand Pro, has been developed and is being tested with individuals with limb loss [4]. This work presents the possibility of applying the SoftHand technology to tackle the issues identified above.

For this reason, we examined the feasibility of combining the benefits of both body-powered and myoelectric prostheses in a hybrid solution focusing on work-oriented applications. This solution uses a shoulder harness to control an externally-powered anthropomorphic prosthetic hand. We started by analyzing the placement of the main moveable components of the prosthesis (motor, battery pack and electronics) on the terminal device, socket, or user's body. Eight potential configurations were selected as feasible solutions, depending on situational requirements. This work presents this analysis as well as one of these solutions, which has been implemented as a functional prototype, the body-controlled, servo-assisted SoftHand Pro-H and featured in the Cybathlon 2016 Powered Arm Prosthesis Race.

Paper Session #5 - Abstracts

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Outcome measures improve following home use with pattern recognition control

Authors: Levi Hargrove, Laura Miller, Kristi Turner and Todd Kuiken

Abstract: Nine people with transhumeral amputations and targeted muscle reinnervation participated in a study to determine how outcome measures change pre and post a minimum 6 week home trial. Each subject controlled a prosthetic arm system comprised of commercially available components controlled using a pattern recognition control system. Subjects showed statistically significant improvements ($p<0.05$) in offline classification error, Target Achievement Control test results, the Southampton Hand Assessment Procedure (SHAP) and the Box and Blocks Test. Their performance also showed a trend toward improvement in the Clothespin relocation task and the Jebson-Taylor test; however these changes were not statistically significant.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Quantifying Muscle Control in Myoelectric Training Games

Authors: Aaron Tabor, Wendy Hill, Scott Bateman and Erik Scheme

Abstract: Myoelectric training games have recently gained interest for increasing motivation and engagement when learning prosthetic control. However, game-based training has not yet been shown to result in improved performance of functional tasks, which has led to a push for "task-similar" training exercises and a questioning of the merit of training games altogether. This apparent lack of observable skill transfer remains counterintuitive, because games can encourage movements similar to those required for prosthesis control. To better understand the effects of game-based training, we identify a set of 'muscle-control metrics' to quantify characteristics of EMG control input that are considered important for 2-site proportional control. In this paper, we introduce these muscle-control metrics and describe a myoelectric training game developed in collaboration with patients and clinicians that is able to capture metrics during gameplay. We also outline an on-going data collection study, which will allow us to identify which aspects of a myoelectric training game lead to improvements in input signals.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: A novel approach to visualising upper limb activity in myoelectric prosthesis users

Authors: Alix Chadwell, Laurence Kenney, Malcolm Granat, Sibylle Thies, John Head and Adam Galpin

Abstract: There are reports in the literature suggesting that around 30% of people prescribed myoelectric prostheses reject their device. Further, there is limited and often rather ill-defined data on usage in people who do not reject their prosthesis. To date, the only method of determining real-world prosthesis usage has been through self-report. Self-report is subject to inaccurate and potentially biased recall and provides, at best, average usage data. The lack of high quality data on real world use of prostheses is very surprising, given one of the core purposes of providing a prosthesis is to restore upper limb function in everyday life.

Activity monitoring offers a method to objectively characterise upper limb activity outside of the clinic. Wrist-worn activity monitors, comprising of tri-axial accelerometers, have been used successfully on numerous occasions to assess the upper limb activity of healthy anatomically intact people and, for example, people recovering from a stroke. Despite the obvious potential to quantify upper limb movements, the use of activity monitors for the assessment of people with upper limb absence has been surprisingly underexplored.

Recently we published the first data using activity monitors to quantify myoelectric prosthesis use [1]; however, the data visualisation method was limited in scope. Arbitrary values were introduced for unilateral activity, a natural log of the usage ratio was taken making interpretation difficult, and temporal patterns of prosthesis usage were not considered. Based on methods which have previously been used for the time series visualisation of whole body activity data, we have developed a new method for displaying upper limb activity. This method uses spiral plots with graduated colours to display the percentage contribution of each upper limb to activity over a week long period. Using this method it is possible to quickly identify the level of symmetry in a person's arm activity, and distinguish patterns of activity between users.

Here we present data recorded from trans-radial myoelectric prosthesis users who report to be both satisfied and dissatisfied users of their prostheses. Participants wore Actigraph GT3X+ monitors on both wrists (anatomical and prosthesis) for a seven day period.

Spiral plots allow for quick identification of patterns in prosthesis use throughout the week; this could be beneficial to both clinicians and researchers. Furthermore, there is the future potential with this method to overlay additional data, such as self-reported wear, or activations of the hand.

[1] Chadwell et al. (2016); Frontiers in Neurorobotics; 10:7

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Environmental barriers to participation and facilitators for myoelectric prosthesis use – a comparison with users of other assistive technology

Authors: Cathrine Widehammar, Helene Lidström and Liselotte Hermansson

Abstract: Background: Myoelectric prostheses (MEP) are used in varying degrees; the number varies between 12-80%[1]. Prosthesis use is greatly affected by the environment, and qualitative research implies that the experience from environmental influence differs depending on how much the MEP is used; daily prosthesis users experience more support and less environmental barriers[2]. To strengthen this conclusion and also to investigate if it is valid for other types of advanced assistive technology (AT), a further study based on quantitative methodology is needed.

Aim: To describe the presence of environmental barriers to participation, and facilitators for MEP use, and to compare this with users of powered mobility devices (PMD) and assistive technology for cognition (ATC).

Method: A cross-sectional survey was conducted with users of MEP, PMD and ATC. The inclusion criteria were: at least one year experience as AT user; age 20-90 years; and communicating in Swedish. The survey contained the Swedish version of Craig Hospital Inventory of Environmental Factors (CHIEF-S) and a study-specific questionnaire focusing on facilitators for AT use. The sample consisted of 156 participants (users of MEP n=51; PMD n=56; and, ATC n=47). The experience of using AT varied between 1-41 years, and many participants used their AT daily (MEP= 80%, PMD=64%, and, ATC=87%). Since the scores were not normally distributed, Kruskal Wallis and 2-tailed Mann-Whitney U test for differences between the groups, and Spearman's rank order correlation were used for analyses.

Results: The top two items acting as barriers to participation in MEP users were Natural environment (temperature, terrain and climate) and Policies government (rules, regulations governed by law). Barriers for participation were significantly less for MEP users than for users of other AT (CHIEF-S total score, md: MEP=0.120, PMD=0.619, ATC=1.560 [$p<0.05$]). In contrast to other AT use, a significant ($p<0.05$) correlation between prosthesis use and barriers to participation was shown in MEP users, with less barriers correlating to more use. Most support came from Related persons and Professionals, and least from Authorities and Rules and regulations.

Discussion & Conclusion: The results confirm earlier qualitative research but show a difference to users of other AT. This should be an avenue for future research. Furthermore, prosthesis usage reported in this study was higher than in most other studies. Hence, the results may not be representative for MEP users in other contexts and this need to be studied further.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: The Clinical Application of a Myoelectric Training Tool for Upper Limb Amputees

Authors: Glyn Murgatroyd, Michael Dawson and Jacqueline Hebert

Abstract: The capabilities of commercial myoelectric devices have been steadily improving; however, the process of training and evaluating amputees in using the technology remains challenging especially as the level amputation or complexity of the technology increases. In order to achieve a successful fitting a balance must be struck between providing a device that is as functional as possible yet not so complicated that amputees have difficulty learning or using it. To help find this balance, an interdisciplinary team from the University of Alberta and Glenrose Rehabilitation Hospital (GRH) developed a Myoelectric Training Tool (MTT) that has similar functionality to commercial prostheses. The MTT includes a desktop robotic arm with 5 degrees of freedom, an electromyography (EMG) acquisition system, an embedded controller, and a laptop with a graphical user interface for fine tuning EMG parameters such as gains and thresholds. In 2015 the MTT was successfully translated to the GRH where it has been used for training of muscle control signals. It is also used for potential myoelectric users try the technology and align their expectations to the current state of the technology before fitting them with an actual device. The clinical team use the MTT to assess the number of degrees of freedom the patient can reliably control, to explore control strategy options, and to start training the patient earlier with tasks closer to what they would be able to do with their final prostheses. In this presentation we will describe the occupational training protocol that we have developed for the MTT along with representative case studies. The protocol includes a number of movement and grasping tasks with graded difficulties that are appropriate for training patients with various numbers of muscles sites including those at the transradial or transhumeral level as well as those that have undergone targeted reinnervation surgery. We have developed a method for finding the best EMG sites using the 8 EMG channels available on the MTT. For patients that lack anatomical landmarks a splint or liner material can be used to improve electrode placement consistency as well as provide compression of the electrode into the muscle belly to improve signal output. Future work will focus on further refining the protocol and including more training options for advanced controllers that use pattern recognition.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Relation between capacity and performance in paediatric myoelectric prosthesis users

Authors: Helen Lindner, Ayako Hiyoshi and Liselotte Hermansson

Abstract: BACKGROUND AND AIM: Myoelectric prostheses are often prescribed to children with upper limb reduction deficiency and training is given regularly by the prosthetic clinics. One goal of prosthesis fitting and training is to give the child a tool to assist when performing daily activities. Prosthetic fitting should be initiated at a young age but little is known whether the prosthetic skills training and recommendations for daily use of prostheses can ease the performance of daily activities. Measures of capacity and performance can help to determine if there is any gap between them that may restrict participation.

The aim was to explore the relationship between capacity scores obtained in a standardised clinical setting and proportional ease of performance in using the prosthesis to perform daily activities obtained from a real-life environment.

METHOD: During their clinic visits, pediatric prosthesis users (n=62, age 3 to 17) were asked to fill in a questionnaire, 'Prosthetic Upper Extremity Functional Index' (PUFI), where the child (or the parent if the child was under 6) rated the ease of performance in using the prosthesis to perform 26-38 daily activities. Then the child performed a bimanual activity and an occupational therapist from the clinic (n=6) assessed the child's capacity for prosthetic control with an observational based assessment, 'Assessment of Capacity for Myoelectric Control' (ACMC). In addition, the child or the parent was asked about the prosthetic wearing pattern. Sex and prosthetic side were recorded. Spearman correlation coefficient and Generalised linear model were used to examine the association between these measures.

RESULTS: A strong correlation (Spearman= 0.75) was found between the capacity scores and the ease of performance. In both unadjusted and adjusted models, capacity was significantly associated with proportional ease of performance. The adjusted model showed that, by 1 unit increase in the ACMC score, the ratio of proportional ease of performance increases by 45%. This implies that ACMC can be a predictor for ease of performance in real-life environment.

DISCUSSION & CONCLUSION: The ACMC as an independent variable was the strongest predictor variable for ease of performance. The results confirm earlier results suggesting a relationship between pattern of use and prosthetic skills. The conclusion is that wearing a myoelectric prosthesis every day facilitates learning of operation skill which, in turn, eases the performance of daily activities. Training for children with myoelectric prostheses should emphasize both establishment of wearing habits and practicing control skills during daily task performance.

Day 3

Thursday, August 17, 2017

Grand Ballroom – Delta Hotel

Day at-a-glance	
8:00AM-9:00AM	Buffet Breakfast
8:30AM-9:00AM	Vendor Workshop: Touch Bionics
9:00AM-9:15AM	Housekeeping
9:15AM-10:15AM	Keynote Address: Dario Farina
10:15AM-10:45AM	Nutrition Break / Vendor Displays
10:45AM-12:00PM	Paper Session #6
12:00PM-1:00PM	Lunch Break / Vendor Displays
1:00PM-2:45PM	Paper Session #7
2:45PM-3:45PM	Poster Session C: Fast-Track Presenters at Podium Nutrition Break / Vendor Displays
3:45PM-4:30PM	Paper Session #8
4:30PM-5:00PM	End of Day Comments
6:30PM-11:00PM	Banquet Dinner

Paper Session #6 - 10:45AM-12:00PM

Themes	Paper title	ID	Presenting Author
Other	A study of the reality of myoelectric prostheses to inform future research	87	Alix Chadwell
	Factors influencing prosthesis use in major upper limb amputees	1	Kristin Østlie
	Classifying and Quantifying Unilateral Prosthesis Use in Home Environments to Inform Device and Treatment Design	47	Adam Spiers
Upper Limb Prosthesis Device Design	The Yale Multigrasp Prosthetic Hand	119	Michael Leddy
	Design of a Low-Cost Prosthetic Hand for Use in Developing Countries	112	Ashley Ballanger
	Development of the HANDi Hand: an inexpensive, multi-articulating, sensorized hand for machine learning research in myoelectric control	51	Dylan J.A. Brenneis

Paper Session #7 - 1:00PM-2:45PM

Themes	Paper Title	ID	Presenting Author
Upper/Lower Limb Myoelectric Control	Robustness of regression-based myoelectric control in a clinical setting	90	Janne Hahne
	Machine Learning to Improve Pattern Recognition Control of Upper-Limb Myoelectric Prostheses	113	Nathan Brantly
	Real-time evaluation of deep learning-based artificial vision for control of myoelectric hands	35	Kianoush Nazarpour
	Performance and satisfaction with intuitive multifunctional hand prosthesis control	24	Ivana Sreckovic
Sensory Feedback	Electrical stimulation of the cervical dorsal spinal cord and rootlets for sensory restoration in upper-limb amputees	103	Santosh Chandrasekaran
	Functional kinesthetic perception of complex bionic hand movements	55	Paul Marasco
	Patient-specific considerations in implementing artificial sensory locations	109	Ivana Cuberovic
	iSens – Progress and Prospect of a Fully Implanted System for Sensorimotor Integration	114	Dustin Tyler
	Home use of a sensory restoration system: Sensation stability and impact on usage	74	Emily Graczyk

Poster Session C: Fast-Track Presenters at Podium – See page 117 for listings and abstracts

Nutrition Break / Vendor Displays

2:45PM-3:45PM

Paper Session #8 - 3:45PM-4:30PM

Themes	Paper Title	ID	Presenting Author
Occupational Therapy & Outcome Measures	Reliability in evaluator-based tests: a modelling approach for interpreting indices of reliability and determining agreement thresholds	53	Dylan Beckler
	Evaluation of daily use and function of conventional body-powered prostheses and custom VO/VC terminal device	117	Kristi Turner
Clinical Prosthetics	Custom Silicone Socket User Survey	13	Jack Uellendahl
	Shroom tumbler ground reaction forces	42	Ed Biden
	Developing the BOA "double cross", adjustable, supra-condylar, transradial socket prosthesis	71	Chris Baschuk
	Addressing the reimbursement challenge: a shift from ADLs to QOL	70	Chris Baschuk

Paper Session #6 – Abstracts

Theme: Other

Abstract Title: A study of the reality of myoelectric prostheses to inform future research

Authors: Alix Chadwell, Laurence Kenney, Sibylle Thies, John Head and Adam Galpin

Abstract: The first clinical myoelectric prosthesis was developed in the 1960's. Since this time research has seen a number of developments, including pattern recognition of control signals, implantable electrodes, and multi-articulating hands. Of these developments, only multi-articulating hands are widely commercially available, suggesting a problem with technology translation. Furthermore, around 30% of myoelectric prosthesis users subsequently reject their prostheses [1]. Amongst the key reasons cited for prosthesis rejection are poor control and poor functionality.

One of the reasons for the very poor rate of technology translation is likely to be the focus taken by many of the research groups in this area on using intact participants in the early phases of research [2]. Of particular note, early phase studies have generally not taken account of the issues associated with transducing signals from socket-located electrodes. Saunders noted that variability in signal transduction is likely inherent to the design of current prostheses [3]. Building on this, the authors have identified three factors from the literature which may impact on prosthesis user performance. These are the skill of the user in controlling the muscle signals, the unpredictability of hand response introduced by a poor electrode fit, and the delay in the hand response due to inherent electromechanical delays. A protocol was developed to assess each of these factors to establish their relative impact on prosthesis user functionality and everyday use of their myoelectric prosthesis [4].

For this study we are recruiting a range of prosthesis users encompassing those who are both satisfied and dissatisfied users of their prostheses, both wearers and non-wearers. Consequently multiple centres across the UK have been involved in the study.

Here we will present preliminary results demonstrating how each of the control factors (skill, unpredictability and delay) relate to measures of user functionality (including task success, task duration, gaze patterns, hand aperture patterns, and movement variability) and everyday prosthesis use (assessed using activity monitoring over the course of a week).

Early results suggest that unpredictable device response is a key factor. Users whose hand reacted unexpectedly were also more reliant on visual feedback as to the hand state, and less likely to wear their prosthesis during the week in which they were monitored.

[1] Biddiss and Chau (2007); Prosthet. Orthot. Int.; 31:3

[2] Vujaklija et al. (2017); Frontiers in Neurorobotics; 11:7

[3] Saunders and Vijayakumar (2011); J. Neuroeng. Rehabil; 8:60

[4] Chadwell et al. (2016); Frontiers in Neurorobotics; 10:7

Theme: Other

Abstract Title: Factors influencing prosthesis use in major upper limb amputees

Authors: Kristin Østlie

Abstract: Arm prostheses are an important aid to function for upper limb amputees (ULAs), and most major ULAs are fitted with prostheses after amputation. Nevertheless, the reported percentage of long-term use and the extent of actual prosthesis use in everyday life among prosthetic wearers vary considerably. Therefore, exploring and understanding factors determining prosthesis use is important to facilitate optimal prosthesis rehabilitation after upper limb loss.

We performed a cross-sectional study analyzing population-based questionnaire data (n=224) and data from interviews and clinical testing in a referred/convenience sample of prosthesis-wearing major ULAs (n=50). Effects were analyzed using linear regression, logistic regression and Cox regression.

Primary prosthesis rejection was found in 4,5%, whereas 13,4% had discontinued prosthesis use. The main reasons for primary nonuse were a perceived lack of need and discrepancies between perceived need and the prostheses available. The main reasons for secondary prosthesis rejection were dissatisfaction with prosthetic comfort, function and control. Primary prosthesis rejection was more likely in ULAs amputated at high age and in ULAs with proximal amputations, whereas secondary prosthesis rejection was more likely in proximal ULAs and in women.

Despite demonstrating good prosthetic skills, prosthesis-wearing ULAs reported actual prosthesis use in only about half of the ADL tasks performed in everyday life. Increased actual use was associated with sufficient prosthetic training and with the use of myoelectric vs. cosmetic prostheses, also in proximal amputees.

Our findings suggest that emphasizing individual needs both in prosthetic fitting and in prosthetic training is likely to facilitate successful long-term prosthesis use. These findings are incorporated in the Norwegian national guideline for rehabilitation after acquired upper limb loss, which includes strong recommendations for individualized prosthetic fitting, mandatory individualized prosthetic training and routine follow-up for prosthetic users. Also, our findings suggest that improved prosthesis quality and fitting of myoelectric rather than passive prostheses may increase long-term prosthesis use and actual prosthesis use in ADL.

References

Østlie K, Lesjø IM, Franklin RJ, Garfelt B, Skjeldal OH, Magnus P. Prosthesis rejection in acquired major upper-limb amputees: a population-based survey. Disabil Rehabil Assist Technol 201;7(4):294-303.

Østlie K, Lesjø IM, Franklin RJ, Garfelt B, Skjeldal OH, Magnus P. Prosthesis use in adult acquired major upper-limb amputees: patterns of wear, prosthetic skills and the actual use of prostheses in activities of daily life. Disabil Rehabil Assist Technol 2012;7(6):479-93.

Evidence-based guideline for rehabilitation after acquired upper limb loss in Norway [Norwegian] Østlie K (editor) et al. MAGICapp 30.03.16. www.magicapp.org/public/guideline/Jn3zaL

Theme: Other

Abstract Title: Classifying and Quantifying Unilateral Prosthesis Use in Home Environments to Inform Device and Treatment Design

Authors: Adam Spiers, Linda Resnik and Aaron Dollar

Abstract: Background: Although there has been substantial efforts to develop new upper limb prostheses, evaluation of such systems is typically conducted through highly structured tests in clinical / laboratory settings or through survey studies. Though such evaluation techniques provide valuable data, they do not characterize how amputees make use of their prostheses in daily life.

Purpose: In our work, we seek to objectively classify and quantify how experienced unilateral upper-limb prosthesis-users utilize their own prosthetic devices and unaffected limbs while completing unstructured and unsupervised manipulation tasks within their own home. Our goal is to identify usage trends in naturalistic everyday activities to inform the design of new prosthetic devices and/or therapeutic interventions.

Methods: Our analysis is based on 'first-person perspective' video recordings from head-mounted lightweight cameras, which can record for several hours at a time. The cameras are pointed towards the hands and arms of participants, who are given a short list of recommended tasks (e.g. vacuuming, brushing teeth) but mostly complete self-chosen domestic 'housework' activities during data collection periods. To date, we have collected 16 hours of video recordings from 3 participants. Two are congenital transradial amputees (one female) who use body-powered devices and one is a male with shoulder-disarticulation amputation who uses a myoelectric powered elbow, wrist rotator and multi-grasp hand. Classification of the observed manipulation strategies led to the generation of a 'Prosthesis-User Manipulation Taxonomy' which accounts for all observed actions via manipulation 'tags' split into three categories of 'Intact Hand', 'Prosthetic Device' and 'Bi-Lateral' with an additional tag for environmental features use to aid manipulation ('Affordance'). The tags consider both prehensile 'grasping' motions in addition to non-prehensile interactions, such as pushing, leaning, clamping objects against the body or hanging objects from the Terminal Device (TD).

Results: Our preliminary results stem from in-depth 'tagging' of segments of the videos using the taxonomy. We have identified several thousand tag instances at an average of 33 manipulation tags per person, per minute. Though recruitment and video analysis is ongoing, initial observations are that non-prehensile manipulation with the TD occurs significantly more often than prehensile manipulation for participants with transradial amputation. This suggests that device design efforts may benefit from focus on non-prehensile features (such as grip pads on the outside of a TD). Conversely, the participant with shoulder disarticulation completed few non-prehensile motions (which rely on arm mobility) but did utilize his multi-grasp TD to perform more prehensile grasps.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: The Yale Multigrasp Prosthetic Hand

Authors: Michael Leddy and Aaron Dollar

Abstract: The last decade has seen significant advancements in upper limb prosthetics, specifically in the myoelectric control and powered prosthetic hand fields. Notwithstanding the improvements in functionality and control of myoelectric prosthetic hands, upper-limb amputees continue to prefer body-powered terminal devices. These body-powered systems have a purely mechanical cable driven actuation scheme that is nominally paired with simple single-grasp terminal devices.

The Yale Multigrasp Prosthetic Hand bridges the gap between body-powered and electric hands. The Yale Hand, a novel body-powered terminal device, is a low-cost anthropomorphic prosthetic hand that incorporates the advantages of multiple grasp types seen in many myoelectric hands. Our body-powered system provides the benefit of proprioceptive force feedback when grasping, requires purely mechanical control, and improves on overall system robustness with no required electrical components. The Yale Hand has three grasp types: power, precision, and lateral grasp that the user can select with a simple movement of the thumb. A single body-powered cable drives all three of the hand's grasps and a modified whiffletree allows the force distribution for each finger to vary depending on the grasp used. The design of the asymmetric whiffletree allows for decoupling and passive compliance in the fingers during grasping. The fingers utilize a pin MCP joint and flexure PIP joint to provide out of plane compliance and an underactuated grasp response. The hand is anthropomorphic, sized to the specifications of a 50th percentile female hand, and features a 3d printed or carbon fiber/epoxy foam chassis. Our novel prosthetic hand preserves the durability, reduced cost and weight, and proprioceptive feedback of a body-powered split hook while encompassing the multi-grasp functionality and aesthetic appeal of more complex robotic hands.

The functionality of the Yale Multigrasp Prosthetic Hand was evaluated through benchtop testing and a twelve-subject able-body study. One unilateral trans-radial amputee and one bilateral trans-radial amputee performed evaluation studies to determine the level of dexterity achieved with the hand. Results show comparable performance to existing commercially available terminal devices on both the Box and Blocks and Southampton Hand Assessment Protocol for the able-bodied and amputee subjects.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Design of a Low-Cost Prosthetic Hand for Use in Developing Countries

Authors: Ashley Ballanger, Ed Biden and Jon Sensinger

Abstract: The World Health Organization (WHO) estimates that there are 25.5 million people with an amputation in developing countries who are living without any type of prosthesis [1]. Even with a lower incidence of upper limb loss than lower limb, there are likely several million people who could benefit from affordable, accessible upper limb prostheses.

When upper limb prostheses are available, users are typically provided a cosmetic hand or a body powered hook. Although a cosmetic hand provides the natural appearance that is often desired by users in less developed countries, it may not allow users to complete all activities of daily living (ADL). Conversely, a body powered hook is technically functional, but users are often uncomfortable with the appearance of the device. A third type of prosthesis, a body powered hand, is rarely used by people with upper limb deficiencies.

Body powered hands have the potential to provide a functional, aesthetically pleasing, and low-cost option to people in need of upper limb prostheses, but current designs are subjected to the highest rates of rejection of all terminal devices. Users have cited a variety of reasons for rejecting body powered hands [2]. At least two of these reasons, high activation force and low pinch force, can be attributed to mechanical inefficiencies in the device [3]. Existing body powered designs have been unable to decouple the actuation and the posture of the hand, leading to devices that actuate too many fingers and have poor efficiency, or actuate only one finger and have a poor selection of postures.

The authors have developed a body powered hand design which combines a single actuation point (the thumb) with the ability to independently pre-position the fingers and thumb. By only actuating the thumb, the device should require less energy to operate than currently available devices. The device is still capable of producing multiple hand postures, including tripod, lateral, and hook grasps, which should allow users to complete many ADLs. In this talk, the authors will present their design, along with data from mechanical and functional tests that compare performance of the prototype to currently available devices.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Development of the HANDi Hand: an inexpensive, multi-articulating, sensorized hand for machine learning research in myoelectric control

Authors: Dylan J.A. Brenneis, Michael R. Dawson and Patrick M. Pilarski

Abstract: Machine learning (ML) has been applied in both research and clinical settings to make myoelectric prostheses more functional and more intuitive to use. ML techniques for myoelectric control require information about the environment a control system occupies in order to make useful control decisions or predictions about a user's desired control outcomes. Despite demonstrated increases in myoelectric control performance with the inclusion of additional information about users and their environments, the sensors in commercial prostheses are limited, and typically do not provide diverse channels of contextual information to their respective control systems. Additional sensor information is crucial to demonstrating and evaluating the full potential of next-generation ML control systems. With this in mind, a novel, cost-effective research prosthesis was designed to provide real-time sensory information for ML-based myoelectric control. This device is able to report fingertip forces on independently controlled fingers, angular position for individual finger joints, and visual information about the hand's environment via a USB webcam integrated in the palm. Using 3D printing, the device was prototyped at a cost of less than $800 CAD. This work therefore contributes a new platform by which groups can conduct ML research on prostheses, and allows researchers to develop new ML approaches with ample access to contextual information about prosthesis movement, prosthesis-environment interactions, and local changes to the environment surrounding the prosthesis. By providing an inexpensive, highly sensorized prosthetic hand, this work helps mitigate the cost of purchasing and retrofitting commercial prostheses with new sensors; it is therefore also expected to support related research into methods for sensory feedback from prostheses to users.

Paper Session #7 – Abstracts

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Robustness of regression-based myoelectric control in a clinical setting

Authors: Janne Hahne, Meike Schweisfurth and Dario Farina

Abstract: A miniaturized low-cost, low-power embedded system for regression-based simultaneous and proportional myoelectric control of a hand prosthesis with two degrees of freedom is presented. In a case study on one subject with transradial amputation, this system outperformed two commonly used conventional control techniques. Furthermore, the robustness of the approach against changing arm position and across sessions without retraining the regression model was demonstrated.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Machine Learning to Improve Pattern Recognition Control of Upper-Limb Myoelectric Prostheses

Authors: Nathan Brantly, Frank Cummins, Blair Lock, Levi Hargrove and Aimee Feuser

Abstract: The clinical application of machine learning to prosthesis control is becoming better understood and more widely accepted. Commercially available pattern recognition systems employ machine learning algorithms to allow users to control their powered prostheses more intuitively, using their unique patterns of electromyography (EMG) signals. As users wear their devices more, the EMG signals they elicit for device control become more consistent [1]. There are factors, however, that can lead to changes in the characteristics of the EMG signals, which serve as inputs to the pattern recognition controller, such as electrode shift, muscle fatigue, et cetera. Currently, no commercially available pattern recognition system makes use of machine learning, supervised-adaptation algorithms to improve control via the utilization of historical EMG data collected during previous calibration routines. This paper introduces clinically relevant approaches and implementations of adaptive machine learning for control of prosthetic and orthotic devices.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Real-time evaluation of deep learning-based artificial vision for control of myoelectric hands

Authors: Ghazal Ghazaei, Patrick Degenaar and Kianoush Nazarpour

Abstract: The loss of any limb, particularly the hand, affects an individual's quality of life profoundly. An artificial arm, or prosthesis, is an example of technology that can be used to help somebody perform essential activities of daily living after a serious injury or health condition that results in the loss of their arm. Assistive technology solutions augmented with computer vision can enhance the quality of care for people with sensorimotor disorders. The goal of this work was to enable two trans-radial amputees to use a simple, yet efficient, computer vision system to grasp and move common household objects with a two-channel myoelectric prosthetic hand. We developed a deep learning-based artificial vision system to augment the grasp functionality of a commercial prosthesis. A convolutional neural network was trained with images of over 500 graspable objects. For each object, 72 images, at 5° intervals, were available. Objects were grouped into four grasp classes, namely: pinch, tripod, palmar wrist neutral and palmar wrist pronated. We implemented the proposed framework in studies involving two trans-radial amputee volunteers to control a commercial i-limb Ultra™ prosthetic hand and a Motion Control™ prosthetic wrist. After training, subjects successfully picked up and moved the target objects with an overall success of about 88% in various visual feedback conditions. The use of a deep-learning based computer vision system has the potential to enhance the functionality of the upper-limb prostheses in clinic.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Performance and satisfaction with intuitive multifunctional hand prosthesis control

Authors: Sebastian Amsuess, Ivana Sreckovic, Birgit Bischof and Thomas Fuchsberger

Abstract: BACKGROUND: Pattern recognition control (PR) functions in a different way than conventional control (CC). Instead of relying on two electrode sites to control a single degree of freedom (DoF), PR uses many electrodes and intuitive movement mapping to control several movements seamlessly.

AIM: The aim of this feasibility study is to test the performance and satisfaction of transradial amputees in prolonged home-use of PR prostheses, and to obtain feedback from certified prosthetists and trainers.

METHODS: Transradial amputees wearing prosthetic systems with CC, single opening/closing hand and active wrist rotation were enrolled in the study. Functional assessments were performed 4 times: 1) baseline with CC prosthesis-baseline, 2) 1st follow-up with the PR prostheses after fitting and training process, 3) 2nd follow-up after 1 month of PR home use, and 4) 3rd follow-up with re-fitted CC prosthesis, and consisted of performance-based (Modified Box and Blocks test (mB&B), Clothespin Relocation and Proportional Control Test) and self-reported tests (Disabilities of the Arm, Shoulder and Hand (DASH); project specific questions). The fitting and training process were rated by certified prosthetists and trainers.

RESULTS: Six patients have been enrolled in the study and fitted with the PR devices. Users were mainly male (71%), mean age 44 (± 13.4) years. Amputation etiology was trauma (100%).

All participants were satisfyingly fitted with PR prosthesis within the first visit. The fitting and training process ware rated as clear or slightly unclear with no or mild difficulty to follow the instructions.

The ability to control hand open/close and wrist rotation, measured with clothespin test, was improved with PR (transporting the clothespins from vertical to horizontal bar showed 34% improvement; from horizontal to vertical bar 18% improvement. The mB&B, was 27s (± 33.8s) prolonged at 1st follow-up and 9s (± 18.8s) at 2nd follow-up. Patients experienced mild difficulty and problems when controlling PR system. No difference was observed in DASH and the level of proportional control. 50% of participants would prefer PR over CC. Users who were already adept CC prostheses users gained disproportionally more from PR than to technically less savvy users.

DISCUSSION & CONCLUSION: PR improved the unilateral gross manual dexterity and ability to control two DoFs. The longer patient accommodation time and optimized product development might minimize mild problems in fine and gross motor movements observed during the first month of PR home-use.

Theme: Sensory Feedback

Abstract Title: Electrical stimulation of the cervical dorsal spinal cord and rootlets for sensory restoration in upper-limb amputees

Authors: Santosh Chandrasekaran, Ameya Nanivadekar, Eric Helm, Michael Boninger, Jennifer Collinger, Robert Gaunt and Lee Fisher

Abstract: Introduction: Numerous studies indicate that sensory feedback could enhance the embodiment, acceptance, and also the ease of use of a prosthetic device. Electrical stimulation of the peripheral and central nervous system is the focus of extensive research as a means to provide sensory feedback. While drawbacks of peripheral nerve stimulation include electrode migration and off-target activation, cortical brain stimulation is an extremely invasive procedure. In contrast, we targeted the dorsal spinal cord and rootlets (DSCR) to provide sensory feedback. This approach affords at least two key benefits. First, the DSCR provide a clear separation between the sensory and motor pathways in the peripheral nervous system. Thus, stimulation at the DSCR will avoid undesired concurrent activation of motor pathways. Second, multiple minimally invasive surgical techniques exist to access the DSCR. In fact, about 50,000 procedures a year are performed in the United States, where spinal cord stimulation (SCS) leads are inserted percutaneously to target the DSCR for alleviating intractable pain. Here, we present observations from human psychophysics experiments performed while stimulating the C5-C8 DSCR in two upper-limb amputees using these FDA-approved SCS leads.

Methods: All procedures were approved by the University of Pittsburgh Institutional Review Board and the US Army Human Research Protection Office. Two study participants with high-level unilateral upper-limb amputations (>16 years and >5 years post-amputation) were implanted with three percutaneous 16 or 8-contact SCS leads (Boston Scientific) respectively, in the lateral epidural space of the cervical spinal cord. Stimulation was delivered using a customized setup for up to 4 weeks, after which the electrodes were removed. Information regarding the modality, location, and intensity of perceived sensations was provided by the subject using a structured reporting system.

Results: Sensations reported by the subjects included focal percepts localized to the amputated arm, hand, wrist, palm, and fingers. The focality of the sensory percepts could be improved by employing current-steering effects through multi-polar stimulation. Although most of the sensations were reported to be paresthetic in nature, subjects did describe some percepts as touch, pressure and movement of fingers and the arm. The focal locations of the sensations were stable for the entire duration of testing. We found that stimulation frequency had the stronger effect than stimulus amplitude on the intensity of perceived sensations and that it also dictated the perceptual modality of the sensation.

Conclusion: With current-steering, DSCR stimulation can generate focal sensory percepts in the missing limb in long-term amputees.

Theme: Sensory Feedback

Abstract Title: Functional kinesthetic perception of complex bionic hand movements

Authors: Paul Marasco, Jacqueline Hebert, Jon Sensinger, Courtney Shell, Johnathon Schofield, Zachary Thumser, Raviraj Nataraj, Dylan Beckler, Micahel Dawson, Dan Blustein, Satinder Gill, Rafael Granja-Vazquez, Jason Carey and Beth Orzell

Abstract: Clinical translation of advanced upper limb prostheses is limited because they do not provide meaningful movement sensation and require constant visual monitoring to complete even the simplest of tasks. Kinesthesia, the sense of body movement, allows us to feel the activity of our extremities without looking at them. This study moves prosthetic feedback into a new perceptual/cognitive framework by harnessing the kinesthetic illusion to provide relevant input to human amputees about complex prosthetic hand movements. In this study, illusion-inducing vibration of surgically reinnervated residual limb muscles in amputees with targeted reinnervation provided physiologically relevant kinesthetic sensation that allowed them to accurately sense and simultaneously control both virtual and mechatronic robotic hand movements in real-time without vision. On a proprioceptive motor task without vision the amputee study participants performed indistinguishably from able-bodied. Psychophysical evaluation of an active motor grip task shows that the kinesthetic feedback alone provides better system resolution than vision alone and when provided with both vision and kinesthesia together they perform optimally. The kinesthetic feedback provided a sense of authorship (agency) over movements and was implemented in clinically realistic 2-site antagonistic myoelectric prosthesis control to provide real-time sensation of hand open and hand close. The feedback system was implementable in physical devices in the context of clinical fitting constraints and the movement percepts can be driven to operate on speed scales relevant to commercially available prosthetic hands. These results open a new path to perceptually-integrated bi-directional bionic prostheses.

Theme: Sensory Feedback

Abstract Title: Patient-specific considerations in implementing artificial sensory locations

Authors: Ivana Cuberovic, Emily Graczyk, Matthew Schiefer, Robert Anderson and Dustin Tyler

Abstract: INTRODUCTION: Sensory restoration is critical for natural prosthesis control. Electrical stimulation of nerves through cuff electrodes restores sensation across the hand. Preliminary studies show that multi-contact stimulation can refine, shift, and create new sensory locations beyond those achievable using single-contact stimulation. Manually tuning these locations is time intensive. Implementing optimized sensations in a clinically viable period requires use of computational models that depend on patient-specific anatomy and cognitive state.

METHODS: To date, four trans-radial amputees have had nerve cuffs implanted on the median, radial, and ulnar nerves. Nerve anatomy and somatotopy was determined using intraoperative ultrasound. After a post-surgical recovery period, subjects underwent a limited mapping study in which they received single-contact stimulation and reported the location of the evoked sensation.

Using the fascicular geometry and initial mapping data, patient-specific models were developed to predict multi-contact stimulation parameters needed to evoke sensation in targeted locations. Finally, subjects underwent a second mapping protocol to map the new and refined sensory locations predicted by these models.

RESULTS: Sensory locations were dependent on cognitive state. Subjects perceived artificial sensations independently of their pre-existing phantom sensation; artificial sensation did not replace the phantom sensation. Thus, we found that the subjects' understanding of their phantom without stimulation affected their perception of the stimulation-evoked sensations. Subjects with poor visualization of their phantom were initially not able to localize sensation on the hand. However, after undergoing visualization training and mirror box therapy aimed at improving subjects' perception of the phantom independent of stimulation, evoked sensations became localized.

Once a clear image of the phantom was established, single contact stimulation elicited unique percepts across the phantom hand for all subjects. As expected, the activated axon population and ensuing sensory location were driven by the fascicular geometry. For example, subjects with more proximal implants reported more diffuse sensations across the hand. Patient-specific models captured these dependencies and enabled us to efficiently determine novel stimulation paradigms in order to evoke sensation in new, functionally relevant locations.

CONCLUSIONS: Providing sensory percepts in functionally relevant locations is dependent on of the patient's nerve anatomy, implant location, and the patient's relationship with their phantom. Patients need a clear understanding of their phantom in order to be able to perceive localized sensations. These locations can be further refined or expanded using computational model derived stimulation parameters.

Theme: Sensory Feedback

Abstract Title: iSens – Progress and Prospect of a Fully Implanted System for Sensorimotor Integration

Authors: Dustin Tyler

Abstract: Since May 2012, peripheral nerve cuff electrodes have been providing direct sensory feedback to individuals with upper extremity limb loss and in lower extremity limb loss since May 2016. In April of 2016 and February 2017, we added new subjects with eight bi-polar myoelectric (EMG) channels for recording muscle activity for simultaneous, arbitrary multi-degree-of-freedom control in the upper extremity. There are a total of 48 nerve or EMG channels implanted on the peripheral nerves and in the muscles, but are routed to external stimulation and recording hardware via percutaneous leads. The sensory restoration system has provided stable feedback over multiple discrete points of the phantom hand since its implant; has eliminated phantom pain is subjects; can provide multiple qualities of sensation; and can provide the same capabilities of intensity discrimination as an intact hand. The implanted EMG electrodes have provided stable, isolated, high signal-to-noise recordings since implant and can provide naturalistic 3 degree-of-freedom control without retaining for over six months.

These results encouraged the development, starting in May 2015, of a clinically-viable, fully-implanted, wireless system to eliminate the percutaneous leads. The implanted somatosensory electrical neurostimulation and sensing (iSens) will drive 64 stimulation channels for restoration of sensory feedback and record from 32 channels, configured into 16 bipolar EMG recording electrodes, for device control. The system will connect to an external device via a high-reliability, low-power Bluetooth wireless link, The systems consists of a central battery and communications module (INC); four "smart leads" that are each connected to the INC via a four conductor lead and then connects to 32 stimulation or recording leads. The sensing smart lead can simultaneously record from 8 bipolar EMG channels with 10-bit resolution at 1000 Hz sampling rate. The stimulation smart lead can simultaneously stimulate twelve channels asynchronously at up to 100 Hz on each channel with patterned intensity stimulation paradigms. The final system will place 32 channels on the median nerve and 16 on each the radial and ulnar nerves. External transmission will be to a Bluetooth dongle connected to personal mobile device or lab laptop computer via USB that serves as the user interface and the main algorithm processor. The Full device engineering and component verification will be completed by end of 2017; full system verification, animal testing, and IDE submission by 8/18; and anticipated approval for clincial study initiation in early 2019.

Theme: Sensory Feedback

Abstract Title: Home use of a sensory restoration system: Sensation stability and impact on usage

Authors: Emily Graczyk, Linda Resnik, Melissa Schmitt and Dustin Tyler

Abstract: Introduction: While neural prostheses to restore sensory feedback to upper limb amputees have the potential to improve task performance and quality of life, studies of sensory restoration systems (SRSs) have only been conducted in controlled laboratory environments. In this study, for the first time, two subjects used a SRS autonomously in a home setting. We report on the technical implementation of the SRS, sensation stability, and participants' attitudes towards and usage of the sensory-enabled prosthesis.

Methods: Two persons with unilateral trans-radial amputation participated. S1 was implanted with 8-channel Flat Interface Nerve Electrodes (FINEs) around his median and ulnar nerves in May 2012, and S2 was implanted with FINEs around his median and radial nerves in January 2013. The SRS consisted of an Ottobock VariPlus Speed prosthetic hand customized with an embedded aperture sensor and fingertip pressure sensors on D1-D3, an external nerve stimulator with a custom sensory stimulation program, and cabling to connect the stimulator to percutaneous leads. The stimulator mapped pressure signals from the finger sensors into stimulation pulse trains and delivered the stimulation to four electrode contacts on the median nerve.

The five-week ABA crossover study involved two 14-day stages without sensory stimulation (A) surrounding one 7-day stage with sensory stimulation (B). Each day subjects completed surveys on sensory stimulation percepts and reported on their performance of items from a list of everyday activities. On-board usage logs monitored wear time and sensor readings. Interviews were conducted to capture subject perspectives on the SRS. Data was compared across stages to evaluate the effect of sensory feedback.

Results: Subjects were able to independently don and doff the SRS, change stimulation settings, and calibrate the prosthetic sensors. Stimulation parameters and sensation locations remained stable throughout the duration of the study. In stage B, with sensory stimulation, subjects wore the SRS longer (sensation on: 8.4 +/- 3.8 hrs (S1), 8.3 +/- 2.2 hrs (S2); sensation off: 4.7 +/- 2.6 hrs (S1), 6.3 +/- 2.0 hrs (S2)), used it more frequently to touch/manipulate objects (S2: $p=0.03$), and reported using their prosthesis to do more activities (S1: $p=0.03$; S2: $p<0.001$). Participants preferred using the prosthesis with sensation enabled.

Conclusions: Two trials of a take home SRS were successfully completed and demonstrate initial feasibility. The SRS was well-received. Interviews and usage logs indicated that subjects preferred using the prosthesis with sensory feedback. Robustness, reliability, and ease of use are critical design features for an SRS.

Paper Session #8 – Abstracts

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Reliability in evaluator-based tests: a modelling approach for interpreting indices of reliability and determining agreement thresholds

Authors: Dylan Beckler, Zachary Thumser and Paul Marasco

Abstract: Indices of inter-evaluator reliability are used in many fields such as computational linguistics, psychology, and medical science; however, the interpretation of resulting values and determination of appropriate thresholds lack context and are often guided only by arbitrary "rules of thumb" or simply not addressed at all. Our goal for this work was to develop a method for determining meaningful interpretation of values, thresholds, and reliability based on a systematic alteration of the mean and variance within a normally distributed error signal, providing insight into the interplay between bias and error of a hypothetical rater population. As a basic metric for inter-rater reliability we selected Krippendorff's alpha. This is a versatile statistical tool for quantifying the agreement between multiple evaluators on sets of observations or measurements and it is highly flexible in handling multiple raters, missing data, and different scales of measure. We presented a video analysis task to three expert human evaluators and averaged their results together to create an initial dataset of 300 time measurements. We developed a mathematical model that then introduced a unique combination of systematic error and random error onto the original evaluator dataset to generate 4800 new hypothetical raters (each with 300 time measurements).We calculated the percent error and Krippendorff's alpha between the original dataset and each new modified dataset to determine the value envelope of inter-rater agreement. We then used this information to make an informed judgement of an acceptable threshold for Krippendorff's alpha within the context of our specific test. As a marker of utility we calculated the percent error and Krippendorff's alpha between the initial dataset and a new cohort of trained human evaluators, using our contextually derived Krippendorff's alpha threshold as a gauge of evaluator quality. We found that this approach established threshold values of reliability, within the context of our evaluation criteria, that were far less permissive than the typically accepted "rule of thumb" cutoff for Krippendorff's alpha. This procedure provides a less arbitrary method for determining a reliability threshold and can be tailored to work within the context of any reliability index.

Theme: Occupational Therapy & Outcome Measures

Abstract Title: Evaluation of daily use and function of conventional body-powered prostheses and custom VO/VC terminal device

Authors: Ashley Swartz, Kristi Turner, Arun Jayaraman and Jon Sensinger

Abstract: The majority of persons with upper limb amputation use body-powered prostheses due to simplicity, robustness, and low cost. However, little is known concerning the daily use, function, and average force exertion for these body-powered devices. In addition, body-powered prosthesis users must choose between a voluntary-opening (VO) and voluntary-closing (VC) device. It is yet to be determined whether a device capable of both VO and VC would provide added benefit and function.

The two main objectives for this study were to quantify the actuation frequency and force exertion for body-powered prosthesis users, and to investigate the impact of a novel VO/VC terminal device capable of being used in both VO and VC modes [1]. Four subjects with a trans-radial amputation were recruited and were fit with an instrumented harness. This harness contained load cell electronics in-line with the Bowden cable and measured the force exerted by the user to actuate the device, as well as the frequency with which the device was used on a daily basis. We also sent the subjects home with the novel VO/VC device, using the same mechanism to track the number of times they used the device as well as how often they switched the device between VO and VC modes. Following the home trial portion, all subjects performed outcome measures of Box and Blocks, Jebsen-Taylor Hand Function Test, Southampton Hand Assessment Procedure (SHAP), and Assessment of Capacity for Myoelectric Control (ACMC) with both their conventional and VO/VC devices, in randomized order. Subjects were also asked to complete a qualitative survey concerning their experiences with the VO/VC device.

All subjects chose to use both modes of the VO/VC device during home use and during the outcome measures. Two subjects performed better at both the Box and Blocks and Jebsen-Taylor using the VO/VC device over their home device. One subject performed better on the SHAP using the VO/VC over their home device. Although the VO/VC device used in this study was experimental all subjects chose to switch modes during both their outcomes and in daily use. This suggests that devices capable of switching modes are useful. The qualitative feedback questionnaires identified room for improvement in the mechanism which could lead to improved outcomes and performance. VO/VC devices in general appear to be useful in daily life and warrant further research attention.

Theme: Clinical Prosthetics

Abstract Title: Custom Silicone Socket User Survey

Authors: Jack Uellendahl and Joyce Tyler

Abstract: The use of High Consistency Rubber (HCR) silicones has been shown to be clinically advantageous for use in upper extremity prosthetics. Until now, no formal review of patient feedback has been reported. Anecdotally, one of the primary reasons that these custom silicone sockets have been preferred by users is the improved comfort they afford. Prosthesis discomfort is often associated with prosthesis abandonment. In order to better understand user's impressions and to determine if wearers do indeed find custom silicone sockets to be more comfortable than non-silicone sockets, a survey was developed. This survey was administered to 25 upper-limb amputees fitted by eleven different Hanger Clinic Upper Limb Specialists. Amputation levels including six wrist disarticulations, sixteen transradials and four transhumeral amputation were represented including one bilateral with wrist disarticulation and transradial amputations. Prosthesis types represented were three passive, seven body powered, and seventeen myoelectric (two users were provided with two types of prostheses using HCR silicone sockets). Eighteen of the twenty-five users reported the silicone socket to be more (n=7) or much more (n=11) comfortable than their previous non-silicone socket. While four reported the same comfort and one user reported less comfort, none reported much less comfort.

Theme: Clinical Prosthetics

Abstract Title: Shroom tumbler ground reaction forces

Authors: Ed Biden, Wendy Hill, Greg Bush, Jenn Porter and Vicky Chester

Abstract: Our clinic has two girls with congenital right transradial limb loss who use the Shroom Tumbler from TRS as their terminal device for competitive cheerleading. The younger of the two had complaints of discomfort in her arm when doing particular tumbling activities. Our objective was to understand what the forces were which were carried by the Shroom as compared to the forces in their sound hands.

The literature is sparse for hand to floor contact forces and we have found no reports for amputees. We have found that the range of observed loads in the hands and wrists of normally limed individuals doing things like back handsprings ranges from less than body weight to about four times body weight.

We used a 12-camera Vicon motion capture system with Kistler force plates to measure various floor exercises used in cheerleading, such as cartwheels and handsprings.

Initial tests showed high forces during tumbling activities. Subsequent changes to the prosthesis included a modified socket which improved her comfort level so that she no longer complains of pain in her sound limb and her prosthetic side. The socket, liner and distal end pads were customized to provide a total contact hydrostatic socket fit. This type of strategy provides a limb, socket interface that can withstand the high peaks in ground reaction forces and provides improved proprioception and stability for gymnastic/cheer activities.

The Shroom provides a good terminal device for cheerleading floor activities but using it should be coupled with coaching which understands the mechanics of the moves and proper form coupled with prosthetic care which can provide an optimal fitting.

Theme: Clinical Prosthetics

Abstract Title: Developing the BOA "double cross", adjustable, supra-condylar, transradial socket prosthesis

Authors: Chris Baschuk and Bob Radocy

Abstract: Self-suspending, or supra-condylar suspension, sockets for short to mid length, transradial amputees have been used successfully for decades. This socket provides a wide range of motion, secure fit and can eliminate cumbersome figure-of-eight harnessing. This design, in various forms and names, is the basis for most electro-mechanical prostheses.

The supra-condylar socket is a challenge to fit well because the bones of the elbow undergo significant displacement during flexion. Too tight of a fit creates unbearable pressure points under load while too loose of a fit compromises prosthesis control. A socket design that is adaptable to the morphological changes that occur during elbow flexion is needed.

The BOA "Double Cross" design was conceived to improve the suspension, comfort and ease of donning/doffing the socket. The side brims of the socket are constructed to be free of the main prosthesis but connected at the rear brim. The rear brim is flexible enough to allow forward motion of the entire brim and the sides of the brim are flexible enough to be contracted together over the condyles capturing the limb within the main socket.

Traditional thermoplastics and laminates lacked the material properties and characteristics needed to meet the design requirements of the BOA "Double Cross" socket. To produce a socket with discrete regions of rigid and flexible material a novel method of fabricating custom multi-durometer silicones was developed.

BOA technology is integrated into the silicone with the control cables running forward internally through both the medial and lateral brims of the socket then "crossing over" each other distally before wrapping around the socket and returning to the opposite brim. This creates a figure-of-eight adjustable lasso around the humeral condyles and the forearm. Un-tensioned, the socket is easy to don and doff. The BOA system can be engaged and tightened to the desired tension trapping the limb securely. Releasing the BOA system allows the brims of the prosthesis to spread back open and the limb is easily removed. Adjustment is simple, so the wearer can change socket tension throughout the day to maintain maximum comfort without sacrificing prosthesis control.

This "BOA Double Cross" design also facilitates those with longer forearms to take advantage of the supra-condylar prosthesis because the flexible brim design creates a larger socket entrance.

A single case study with an experienced transradial amputee was performed with good success by Handspring Prosthetic Rehabilitation.

Theme: Clinical Prosthetics

Abstract Title: Addressing the reimbursement challenge: a shift from ADLs to QOL

Authors: Chris Baschuk and Pat Prigge

Abstract: Contemporary upper-limb prosthetic technologies become clinically irrelevant if payers are not willing to reimburse for them. Risk-averse prosthetists are hesitant to embrace and apply newer technologies even when they are the most appropriate choice to provide their patients with the desired functional outcome. These insurance-driven clinical decisions may be one factor in the historically high level of patient rejection of, and dissatisfaction with, upper-limb prostheses.

Exclusionary language is written in many insurance policies regarding upper-limb prosthetic components. A common reason for non-coverage of specific items is that the technology is considered "experimental and investigational" due to a lack of clinical research proving their effectiveness even when they may have been used clinically with success for many years. Multi-articulated hands, powered digit systems, and any prosthesis for an amputation distal to the wrist are most frequently excluded.

As a profession, the focus has been on defining clinical success as meeting ADL requirements. The definition of ADLs used by insurance companies is based on the theoretical independence of a young child. Particularly, it was intended to assess the care needs of elderly persons: including SNF admittance. This is outdated and does not represent upper-limb prosthetic patients' demands of a pre-injury QOL. There is insufficient clinical evidence specifically quantifying the functional and psychological benefits of contemporary upper-limb prosthetic technologies with respect to improved QOL. Other healthcare fields report and quantify QOL because it provides a broader spectrum in which clinical success is defined. A paradigm shift from assessing and reporting ADLs to QOL in upper-limb prosthetic rehabilitation would help improve our clinical justifications for reimbursement.

The leadership of the Upper-Limb Prosthetics Society of the AAOP is addressing this issue by helping to coordinate and publish research surrounding these contemporary clinical technologies. We have begun to investigate the policies of these insurance companies and tried to determine the requirements that these companies have in place in order for policy guidelines to be changed. The purpose of this presentation is to create awareness surrounding what these requirements are and to initiate a discussion amongst the professionals in attendance at MEC. This is an effort that will need a coordinated international collaboration between manufacturers, clinicians, researchers, physicians, and patient advocacy groups to be successful. Our goal is to establish a body of evidence that can be freely shared amongst those caring for individuals with upper-limb differences so that these prejudicial policies can be overturned.

Day 4

Friday, August 18, 2017

Grand Ballroom – Delta Hotel

Day at-a-glance	
8:00AM-9:00AM	Buffet Breakfast
8:30AM-9:00AM	Vendor Workshop: Infinite Biomedical
9:00AM-9:15AM	Housekeeping
9:15AM-10:00AM	Paper Session #9
10:00AM-11:00AM	Panel Discussion: 3D Printing
11:00AM-11:30PM	Nutrition Break / Vendor Displays
11:30AM-12:45PM	Paper Session #10
12:45PM-1:00PM	Closing Remarks
1:00PM-2:00PM	Boxed Lunch Vendor tear down

Paper Session #9 - 9:15AM-10:00AM

Theme	Paper title	ID	Presenting Author
Upper Limb Prosthesis Device Design	Implementing rapid prototyping with current technology to enhance overall function for blind bilateral patient	5	Matthew Mikosz
	Surface myoelectric signal adjustment for upper limb prosthesis control applying RT system	127	Kengo Ohnishi
	Simultaneous Control of a Virtual Multi-Degree of Freedom Prosthetic Hand via Implanted EMG Electrodes	92	Matthew Williams
	A preliminary study towards automatic detection of failures in myocontrol	82	Markus Nowak

Paper Session #10 - 11:30AM-12:45PM

Theme	Paper title	ID	Presenting Author
Clinical Prosthetics	Outcomes of the clinical application of pattern recognition in upper limb prosthetics: a two-year retrospective	72	Chris Baschuk
	The Utilization of Pattern Recognition Control for the Transhumeral Amputee without TMR surgery: Clinical Experiences	111	Craig Jackman
Upper Limb Prosthesis Device Design	Perceptual and control properties of a haptic upper-limb prosthetic interface	50	Dick Plettenburg
	Early Clinical Results of a New Aesthetic Heavy-Duty Electric Terminal Device	28	Scott Hosie
	Impact of Upper Limb Prosthesis Simulators	17	Debra Latour
	Case Study: Experience Fitting Heavy Duty Stainless Steel 3D Laser Sintered Locking Finger on a Partial Hand Amputee	3	Branden Petersen

Paper Session #9 – Abstracts

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Implementing rapid prototyping with current technology to enhance overall function for blind bilateral patient

Authors: Matthew Mikosz

Abstract: This presentation will discuss the design and fitting process for a blind, bilateral partial hand/ trans-radial amputee who also underwent a face and jaw transplant after an attack by a chimpanzee and the rationale behind choosing the specific design that was implemented. After a thorough evaluation with the patient by the physician, upper limb specialist and Occupational Therapist it was determined that the patient could benefit from being fit with some of the latest myoelectric technology with some modifications to maximize her function. The technology that was chosen for her on the left trans-radial side was a myoelectric prosthesis with I-Limb Quantum, electric wrist rotator and custom silicone socket interface. The right partial hand was a custom made implement holder that was designed in CAD and 3D printed. The purpose of this presentation is to highlight the benefits of rapid prototyping and how implementing with current technology can enhance the functional outcomes for the user. Utilizing the I-Limb Quantum with electric wrist rotation had proven to have many benefits that improved her activities of daily living but also presented some challenges. The wrist rotator presented the most challenges as being blind she was unable to determine where the hand was in space. This challenge was anticipated and led to the design of a wrist rotation limiting device that was placed in between the hand and prosthesis to limit the motion of the wrist rotator. The range of motion determined to be required for functional activities was around 90 degrees. This allowed her to always know where the hand positioning was based on an audible beep from the wrist rotator when the limits were achieved. The right partial hand device was designed specifically for her to better assist her with feeding herself, writing and grooming. Several designs were developed over the week and incorporated into her therapy sessions. At the end of the week the optimal design was printed and implemented into her prosthesis. This fitting has shown that currently available technology alone can have great benefits for the user but when limitations or challenges arise some modifications or additions can compound the benefits and overall success for the user.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Surface myoelectric signal adjustment for upper limb prosthesis control applying RT system

Authors: Kengo Ohnishi, Kimihiro Hayashi and Jumpei Oba

Abstract: Myoelectric controlled prosthetic hand has advantage of generating larger gripping force than the muscular force of the residual limb. This characteristic benefits small children to conduct tasks more easily. The hindrance of fitting myoelectric hand to small children is caused by the low reliability of myoelectric control at introduction due to low-reproducibility of non-adjusted myoelectirc sensor signal. The dialogical adjustment of the sensor applied to the schoolable child is not promising to younger children where basic assumption of repetitive concentrated muscle activations is questionable.

To overcome this problem, we propose on applying a realtime pattern recognition method, RT System, to myoelectirc sensor signal to skip the initial gain adjustment of the sensor amplifier. Recognition Taguchi (RT) system which is a modified strategy of Mahalanobis-Taguchi System is a statistical process that numerically scales the similarity of the sampled data cluster with the model data cluster by calculating two characteristic parameter, Signal-to-Noise ratio and sensitivity. The root-mean-square is computed from the two parameters generated from the groups of model data cluster and sampled data cluster. Then the root-mean-square distribution of the model data cluster is used to evaluate the difference of the sampled data.

As a pilot experiment, a conventional 3-pole dry electrode with analog filter and amplifier was used to sample raw myoelectric signal at 3kHz. A 60Hz-notch filter and 5-to-500Hz band-pass filter was applied digitally as pretreatment. Forearm extensor myoelectric signals of 2 male subjects, in their twenties, were recorded at the most suitable point and the most degraded point for 15s, respectively. For the RT system processed signal, series data of the first 0.33s window after discarding the initial 3s data of recording was set as the model data cluster in each collected sample. Ten seconds of the remaining collected data was processed as sample data. The RT system processed signal was compared to the conventional full-wave rectification, RMS-smoothing, envelope processed signal. While the conventional filtered data did not have clear contrast in degraded condition, RT system processed signal had muscle activation signals to be 200 times larger potentials compared to the signal at resting condition.

The RT system processed signal had superior amplification even for a subject with a thick subcutaneous fat that caused difficulty of operating an on-the-market myoelectric hand with conventional myoelectric sensor. However, the subject and experimental conditions were limited and further experiments are needed, especially with toddler, after safety concerns are cleared.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: Simultaneous Control of a Virtual Multi-Degree of Freedom Prosthetic Hand via Implanted EMG Electrodes

Authors: Hendrik Dewald, Platon Lukyanenko and Matthew Williams

Abstract: The loss of a hand can have a profound, life-altering impact on an individual's life. Recent advances in dexterous myoelectric hands now afford a device that can come close to replicating the range of grasp shapes possible by the natural hand. However a bottle-neck remains regarding the ability to naturally convey enough information to control the multi-degree of freedom (DOF) hands now available. This work describes the deployment of an intuitive multi-DOF command interface that uses permanently implanted EMG electrodes in the muscles of the residual limb and machine learning techniques to decode user motor intent.

This paper covers the results of the first recipient of such a system. The implanted portion consists of eight bi-polar EMG electrodes surgically placed within the proximal muscles of the wrist and fingers. The leads were tunneled under the skin to the upper arm and exit percutaneously. A cued posture matching task was used to train the system to recognize user intent to control the simultaneous velocity of three degrees of freedom – hand aperture, wrist flex/extension, and wrist rotation. An artificial neural network (ANN) was used to convert key magnitude and frequency-related features of the EMG signals into continuous joint velocity. An ensemble approach was used whereby the coincident features of all eight EMG signals are used as inputs instead of the one-muscle, one-action agonist/antagonist command approach used in more conventional myoelectric prosthetic hands. A virtual reality (VR) posture matching task was used to test system performance. The performance of the intact hand was used as a standard for comparison.

The results of this work have shown that the implanted electrodes offer superior signal to noise ratio and less electrical interaction between electrode pairs than that seen using surface EMG recordings. User signals for specific hand motions have been consistent over several months, allowing for literal plug-and-play operation without the need for regular re-calibration. Compared to the intact hand, the ANN decoded movements exhibited no significant difference ($p > 0.05$) in terms of Trial Time (3.39±0.13 vs.2.82±0.21 s), Overshoot (41±8% vs.48±8), or Success Rate (100%), though they did exhibit a slightly reduced Path Efficiency (57±2 vs. 66±2%) and slower Movement Speed (18±0.5 vs. 22±0.4 %ROM/s).

This work demonstrates the potential benefits of coupling machine learning techniques with implanted ensemble EMG recording. Improvements in signal quality yielding more consistent signals can possibly afford prosthetic hand performance on par with the intact hand.

Theme: Upper Limb Prosthesis Device Design

Abstract Title: A preliminary study towards automatic detection of failures in myocontrol

Authors: Markus Nowak, Sarah Engel and Claudio Castellini

Abstract: Reliability is still the main issue in myocontrol: enforcing (dexterous) grasping, releasing and motion exactly and only when the amputated subject desires it. One specific path towards the solution of this problem is incremental machine learning, leading to interactive myocontrol, in which unreliability is taken care of via on-demand model updates, requested by the experimenter and/or the subject herself. One natural drawback of this approach is that an "oracle" is needed at all times, stopping the prediction and calling for an update whenever this is deemed to be the case; an automated oracle, as reliable as possible, is therefore very desirable.

This work shows the results of a preliminary study in which we tried to find features of the control signals and predictions, as well as environmental information (inertial sensors and motor currents) to automatically identify the failures of the myocontrol system. The outcome is promising, showing that a classifier can match the observer's judgement with an accuracy of slightly more than 75%.

Paper Session #10 – Abstracts

Theme: Clinical Prosthetics

Abstract Title: Outcomes of the clinical application of pattern recognition in upper limb prosthetics: a two-year retrospective

Authors: Chris Baschuk, Laura Katzenberger, Debra Latour, Thomas Passero and Erik Tompkins

Abstract: Presented here is a series of case studies describing the successes and challenges that were experienced, as well as the innovative solutions that were developed, during the real-world clinical application of pattern recognition (PR) technology over the course of a two-year period.

Over the course of two years a total of 13 patients were fit by Handspring Prosthetic Rehabilitation Services with PR technology. Three females and ten males in total. Five patients had a transradial amputation level, seven patients had a transhumeral level amputation, and one patient had a shoulder disarticulation level amputation. One of the patients with a transhumeral level amputation also uses a body powered transradial prosthesis on his contralateral side. One of the patients with a transradial presentation had a congenital limb difference.

Two of the four patients in the transradial group discontinued use of PR. One discontinued use due to general non-compliance, the other discontinued use due to the extra bulk in the prosthesis created by the additional COAPT components.

All of the patients with transhumeral level amputations continue to utilize their PR systems with the exception of the patient with bilateral amputations. This patient was a long-time user of body-powered technology and decided to abandon any attempts at using external powered prostheses.

The one patient with the shoulder disarticulation was initially successful with utilization of the PR technology, but due to health complications secondary to a brachial plexus injury necessitated that the external powered prosthesis be abandoned in favour of a lighter weight custom silicone restoration.

Initially all patients were able to consistently control their prostheses with increased accuracy over the course of their post-delivery occupational therapy.

All patients initially subjectively reported being satisfied with the fit, function, and comfort of their prostheses.

All patients actively utilize the calibration feature of the COAPT system daily when they don the prosthesis for optimal control. Everyone reported that this feature was very important to them.

These case studies demonstrate that the PR technology available from COAPT can be utilized successfully in externally powered prostheses for patients with all levels of upper limb differences. It was the experience of the patients and clinicians at Handspring that the clinical application of PR technology resulted in a 70% myoelectric prosthetic acceptance rate. It was our anecdotal experience that patients fit with the COAPT system were able to progress faster in their OT training than other patients.

Theme: Clinical Prosthetics

Abstract Title: The Utilization of Pattern Recognition Control for the Transhumeral Amputee without TMR surgery: Clinical Experiences

Authors: Craig Jackman and Jason Macedonia

Abstract: Pattern recognition control has been commercially available since 2013 when COAPT released its Complete Control system. At the time of its launch, the clinical perception of the candidate selection for this control option was focused on those individuals who were proximal level amputees with TMR surgery. While it has been well documented that individuals with TMR surgery preferred pattern recognition control over direct control (1), the use of pattern recognition with non TMR proximal level amputees is yet to be definitively studied with commercially available prostheses. This presentation will share the author's experiences using COAPT's Complete Control system with two non TMR transhumeral amputees. Both of these individuals were previously fit with traditional direct control prostheses. In sharing these experiences, it will include the successes and challenges encountered in fitting these individuals with their prostheses as well as the perceptions of the users when comparing direct control with pattern recognition. The hope in sharing these cases is to inspire further investigation into utilizing pattern recognition for this population where an inclusion criteria can be established for pursing this technology.

1-Hargrove, Levi J., Blair A. Lock, and Ann M. Simon. "Pattern recognition control outperforms conventional myoelectric control in upper limb patients with targeted muscle reinnervation." Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE. IEEE, 2013.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Perceptual and control properties of a haptic upper-limb prosthetic interface

Authors: Alistair Vardy, Manon Boone and Dick Plettenburg

Abstract: Current upper-limb prostheses fail to meet user expectation. Common complaints are the large control forces for body-powered prostheses (BPP) and the lack of proprioceptive Sensory Feedback in myo-electric prostheses (MEP). This study investigates sensitivity and control accuracy and feedback sensitivity of a haptic (master-slave) interface that combines BPP-like control for a MEP utilizing low control forces in the presence of proprioceptive feedback. This first step focuses on static forces. One experiment focused on the just noticeable differences (JND) and the Weber fraction (WF) of the shoulder, and a second on force control. JND and WF were determined by a two-alternative-forced-choice-method at 4 forces levels (2, 4, 6, and 8 N). Force control was evaluated by a visual matching task and blind reproduction task at the same force levels, and force error (FE) and force variability (FV) were obtained. WF results (7% for 2 N, 3% for 4 N, 3% for 6 N and 2% for 8 N) indicated a level of sensitivity comparable to human weight perception. FE and FV values were small enough as not to affect usability when grasping objects. We conclude that forces of 2-10 N are sufficient to operate an externally powered prosthesis while maintaining a sufficient level of proprioceptive feedback.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Early Clinical Results of a New Aesthetic Heavy-Duty Electric Terminal Device

Authors: Harold Sears, Ed Iversen, Jeff Christenson and Scott Hosie

Abstract: Over the last decade, a heavy-duty Electric Terminal Device (ETD1) has been adopted widely by Upper Extremity (UE) amputees, featuring a water-resistant housing, combined with simple but functional hook fingers, motor-driven by a 2-speed transmission.

A new version was sought with goals to: 1) shorten the overall length 2) implement body-powered grip shapes to improve grip security (developed in an earlier project) [1], 3) improve aesthetics so that wearers could use a hook-style TD in a wider range of workplaces and social situations.

A new design, ETD2, using metal and plastic structure, achieves the goal of shorter length, and a smoother aesthetic, while retaining high durability, water and dirt resistance, low weight, quick response, and high pinch force, as in the legacy device. The grip surfaces are replaceable in the field, an important convenience.

The on-board electronic controller allows interchange- ability with almost all other terminal devices, Bluetooth® wireless communication, and Force Limiting Auto Grasp (FLAG) [2].

The field trial subjects (n=8) were unilateral UE prosthesis wearers. Results indicate equivalent function to the ETD1 in most areas, with interesting divergence of opinion in areas.

The usage period (from 2-18 mo.) yielded a wealth of information, guiding the design process. Summarizing the comparisons to ETD1:

- Cylindrical and flat gripping surfaces were uniformly rated superior.
- Rubber areas on lateral fingertip surfaces aided in pushing down and holding firmly, etc., for most wearers.
- Field-replaceable gripping surfaces promise to reduce the current area of highest maintenance.
- Speed and responsiveness for many was quicker than ETD1.
- Shorter overall length was valued, and produced lighter perceived weight for some.
- The aesthetics of ETD2 are appreciated, but not consistently by all. Color choices strongly favored black.
- The wider hook fingers of ETD2 meant a loss of visibility for some (but not all).

Generalizations

- UE prosthetic wearers as a group are enthusiastic to have more choices – as long as they do not represent a major compromise in function.
- The varieties of TD functions are different for each wearer – ensuring that opinions are very seldom consistent across all wearers.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Impact of Upper Limb Prosthesis Simulators

Authors: Debra Latour

Abstract: Evidence has been published regarding the beneficial impact of prosthesis-simulators. Bittermann (1968) cites use of such simulators with the non-amputee. This concept has been utilized for decades to impart empathy and to facilitate understanding operation of the body-powered technology. Weeks et al (2003) discusses the use of a simulator with uninvolved upper limb to successfully transfer skill of prosthesis use to the involved upper limb. Teaching individuals with upper limb deficiency to become adept with the prosthesis, its use and integration of it into acquisition of skills related to activities of daily living, work, recreation and social interactions can be challenging. As any practitioner of occupational therapy services knows, it is integral for beneficial outcomes that caregivers and other family members be involved in the process. Carry-over of recommendations for all aspects of wear schedule of the prosthesis, skills-drills activities and adaptive strategies and techniques is essential for the successful outcomes of functional independence and positive perceived quality of life. Family members and other caregivers may be present during the prescriptive and therapeutic phases of the prosthetic program, but often lack first-hand experience of wearing/utilizing an actual prosthesis. Simulators of limited technology, such as a voluntary-opening device may be available to provide limited experience, but not readily accessible on an ongoing basis. This technology is typically used to provide a forecast to the consumer relative to expectations. Such simulators have also been used with clinicians and peer groups to advocate empathy and respect for individuals with UL differences and to enhance understanding of what is involved to strategically utilize body-powered prosthetic technology.

Theme: Upper/Lower Limb Myoelectric Control

Abstract Title: Case Study: Experience Fitting Heavy Duty Stainless Steel 3D Laser Sintered Locking Finger on a Partial Hand Amputee

Authors: Branden Petersen C P L P, Richard Weir Ph D, Levin Sliker Ph D, Jacod Segil Ph D and Stephen Huddle M S

Abstract: Partial hand and finger amputations make up the largest upper limb patient population when you look at upper limb amputation as a whole. In the past several years there has been many advances towards options for patients with partial hand amputations. Many of these advances can assist improving the functionality of partial hand amputees. Many partial hand patients are involved in many different activities of daily living (ADLs) that are heavy duty. In the past many of the partial hand prosthetic options do not hold up to heavy duty forces, wet,and dirty environments. Point Designs LLC recently developed a 3D laser Sintered stainless steel prosthetic locking finger designed for heavy duty ADLs. This case presentation is about a 34 year old Caucasian male that works in the building and construction industry. He Sustained a work related injury that resulted in a partial hand amputation of fingers 2-5 and thumb tip. Due to the heavy duty nature of his work a heavy duty prosthesis was required. This presentation discuses the features of this new 3D printed stainless steel locking finger and clinical application.

Poster Session A

Day 1: Tuesday, August 15, 2:45PM-3:45PM

Theme	Paper title	ID	Presenting Author
Other	Provision of active upper limb prostheses around the world.	10	Andreas Kannenberg
Upper/Lower Limb Myoelectric Control	Future look of upper limb prosthetics	15	Lars Hellmich
Clinical Prosthetics	Advancements in Clinical Application of Custom Silicone Interface for Pediatric Prosthetics	21	William Yule
Upper/Lower Limb Myoelectric Control	Prosthetic acceptance in children and factors that can influence it - a literature review	25	Ivana Sreckovic
Clinical Prosthetics	Choosing a myoelectric hand and hardware that suits the unilateral amputee's functional requirements	30	Judith Davidson
	Integration Of Comfort And Control For UL Treatments	31	Erik Andres
	The Use of Custom Silicone for a Sport-Specific Partial Hand Prosthesis: Design and 4 Month Follow-up	32	Kyle Sherk
Occupational Therapy & Outcome Measures	Evaluation of hand function transporting fragile objects: the Virtual Eggs Test	40	Marco Controzzi
	Kinematic insights from a novel gaze and movement metric for upper limb function: normative and prosthetic comparison	43	Aida Valevicius
Upper Limb Prosthesis Device Design	Two-DoF, Dynamic EMG-Based Estimation of Hand-Wrist Forces with a Minimum Number of Electrodes	44	Edward Clancy
Occupational Therapy & Outcome Measures	Descriptive outcome metrics of sensorized upper limb performance using optimal foraging theory	52	Dylan Beckler
Upper Limb Prosthesis Device Design	Influence of a transradial amputation on neuromuscular control of forearm muscles	57	Morten Bak Kristoffersen
Upper/Lower Limb Myoelectric Control	A Self-Grasping Hand Prosthesis	59	Gerwin Smit
Occupational Therapy & Outcome Measures	Service Members and Veterans with Transhumeral Osseointegration: Initial Rehabilitation Experiences from the DoD OI Program at WRNMMC	65	Annemarie Orr
Sensory Feedback	Measuring User Experience of A Sensory Enabled Upper Limb Prosthesis	67	Linda Resnik
Upper Limb Prosthesis Device Design	Real-time classification of five grip patterns with only two sensors	80	Agamemnon Krasoulis
	RTM-PDCP linkage platform multi-modal sensor control of a powered 2-DOF wrist and hand	85	Masaki Shibuya

	Pattern Recognition Myoelectric Control Calibration Quality Feedback Tool to Increase Function	88	Frank Cummins
Occupational Therapy & Outcome Measures	The Control Bottleneck Index: a novel outcome metric providing generalizable and actionable assessment of upper-limb prosthetic systems	96	Dan Blustein
Upper Limb Prosthesis Device Design	Channel Selection of Neural and Electromyographic Signals for Decoding of Motor Intent	102	Jacob Nieveen
Upper/Lower Limb Myoelectric Control	The PSYONIC Compliant, Sensorized Prosthetic Hand	124	Aadeel Akhtar
Upper Limb Prosthesis Device Design	Giving Them a Hand: Wearing a Myoelectric Elbow-Wrist-Hand Orthosis Reduces Upper Extremity Impairment in Chronic Stroke	126	Lauren Wengerd
	Deriving Proportional Control for Pattern Recognition-Based Force Myography	132	Alex Belyea

Poster Session A – Abstracts

Theme: Other

Poster Title: Provision of active upper limb prostheses around the world.

Authors: Andreas Kannenberg

Abstract: Introduction: A recent systematic review of the literature has shown that there is no evidence for a general functional superiority of body-powered or myoelectric/externally powered prostheses, but cosmesis and appearance of myoelectric hands were significantly better [1]. The purpose of this paper is to give an overview on the perspective of different health care systems around the world on the coverage of active upper-limb prosthetics.

Method: As no authoritative statistics are publicly available, data was collected by interviewing acknowledged professionals in the field of upper-limb prosthetic rehabilitation as well as by obtaining estimates of market sizes for body-powered and myoelectric/externally powered upper-limb prostheses from Ottobock´s business unit, national market managers, and clinical prosthetists specialized in upper-limb prosthetics in various countries.

Results: Countries may be placed in one of three categories upon the basic approach to the provision of active upper-limb prostheses:

1. Health care systems that grant access to all types of active upper-limb prostheses (e.g. Western and Northern Europe). In these countries, myoelectric/externally powered upper-limb prostheses are considered standard of care. However, adoption levels vary depending on differences in coverage policies. In countries whose healthcare systems cover several upper-limb prostheses at a time, 80-90% of patients use myoelectrics as their primary prosthesis. If the healthcare system covers only one prosthesis at a time, the proportion of myoelectric prostheses may decline to 50-60%.
2. Health care systems that limit access to active upper-limb prostheses primarily to body-powered devices (e.g. USA, Canada, Australia, New Zealand, Japan). In these countries, myoelectric/externally powered prostheses require approved exceptions from coverage policies and are typically used by less than 35-40% of all patients with active prostheses. However, in some specialized urban rehabilitation clinics, the share of myoelectric prostheses may reach up to 70%.
3. Countries with health care systems that provide passive or no upper-limb prostheses to the vast majority of their beneficiaries (e.g. Eastern Europe, Latin America, Asia, Africa).

Discussion: Although the scientific evidence for upper-limb prosthetics is the same around the world, coverage policies and funding vary remarkably and result in strikingly different adoption rates of active upper-limb prosthetic technologies between different countries. Among industrialized countries, the most important difference seems to be whether policies only consider prosthetic function or also psychosocial aspects for determining medical necessity of the available active prosthetic technologies and designs. Unfortunately, no data is available to conclude which strategy results in higher prosthesis acceptance rates.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: Future look of upper limb prosthetics

Authors: Lars Hellmich, Barbara Hammacher, Ivana Sreckovic and Birgit Bischof

Abstract: In the last decade the appearance of mulitarticulating hand designs has created a new trend in technology and cosmesis with launch of the i-limb (Touch Bionics) in 2008 and the Michelangelo Hand (Ottobock) in 2010. Besides improved functionality the desired prosthetic look has changed from a natural and physiologic appearance to more futuristic presentation. The demographic factors for desired appearance still remain largely unknown.

The goal of this ongoing design analysis is to consider international trends for the future look of upper limb (UL) prosthetics. This design analysis represents a quantitative market research of Orthotics and Prosthetics (O&P) professionals from North America, Germany, Austria, Australia, South Africa, Spain, Italy, Finland, Russia, Turkey, Poland, China, Japan, South Korea and Sweden. Possible contributing factors identified were current timeline, the users' gender, age, activity level, cultural background and the professional's knowledge of current prosthetic technology.

The survey has been posted since November 7th, 2016 in 16 different countries. The planned availability of the survey will be until July 2017. Current results are based on 49 responses of O&P professionals. The results, given in figure 1, show the expected trends towards natural and futuristic looking prosthesis regarding: timeline, gender, age, activity level, background and the O&P knowledge of the state of the art prosthetic technology and Up-to-Date level of O&P professional (UtD). In the past, only 10% of users preferred futuristic UL prosthetic appearance, while in future this number might increase up to 51%. Correspondingly, 73% preferred a natural look in the past and 16% might prefer this appearance in the future. Females tend to prefer natural prostheses (85%), whereas men might have a tendency for futuristic prostheses (51%). Of younger prosthetic users 45% (0-12) would prefer the futuristic/robotic like look, while this form of prosthesis would be chosen by 8% of people with UL deficiency older than 65 years of age. Active people have a tendency for a more futuristic look (73%) than less active people, who would rather choose a natural one (82%).

According to the overall feedback from O&P professionals regarding expectations of user´s preferred future upper limb prosthetic appearance, the trend seems to indicate a more futuristic/robotic appearance, though age and gender play an important role for the individual fitting. Older users preferred a natural look, while males tend to favor futuristic prosthetic appearance.

Theme: Clinical Prosthetics

Poster Title: Advancements in Clinical Application of Custom Silicone Interface for Pediatric Prosthetics

Authors: William Yule, Bill Limehouse, Branden Petersen and Patrick McGahey

Abstract: The current technology of custom silicone sockets for pediatric upper limb prosthetics has been advantageous to the pediatric patient population. Historically, pediatric prosthetic systems have been designed to meet developmental needs as a child progresses and ages with onion skin design and other flexible socket interfaces. With the advent of custom silicone socket interfaces the pediatric upper limb patient population has benefitted in more comfortable, flexible and durable myoelectric and conventional upper limb prosthetic systems.

Prosthetic practitioners have utilized various commonly accepted practices when fitting the pediatric patient. Custom silicone socket systems are now more readily available than in previous years and have presented more advantages to successful fittings than previous designs. The ultimate goal of this technology is to improve the clinical outcomes for the pediatric patient population through a better socket interface which adds comfort, flexibility and better acceptance of the prosthesis. Case studies and application will be presented to show the benefits and results applicable to this technology.

This presentation will familiarize the healthcare professional of silicone technology and its application advantages in the clinical setting as it relates to fitting this patient population. Options and methodology will be presented to educate health care practitioners as it applies to the fitting and functional applications in the clinical practice for the pediatric upper limb loss patient.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: Prosthetic acceptance in children and factors that can influence it - a literature review

Authors: Ivana Sreckovic, Milana Mileusnic and Andreas Hahn

Abstract: Introduction: Children with upper limb deficiency usually do not have sense of limb-loss, and often see a prosthesis as an assistive tool, rather than a functional hand replacement1. Therefore a child will accept and wear a prosthesis only if it is regarded as useful2. The objective of this review was to evaluate the factors that might influence upper limb prosthetic acceptance in children fittings.

Methods: Pubmed search was performed to identify the publications with upper limb prosthetic acceptance in children. The published articles additionally known to the authors were reviewed and if relevant included. Quality assessment of the studies was not conducted.

Results : Eleven articles were identified as appropriate and included in the review.

41% of children were multiple prosthetic users3. Of those children who used only one prosthesis, 44% selected a simple passive hand as their prosthesis of choice, 41% a body-powered and 15% a myoelectric prosthesis3. Another study reported that 36% of children accepted a passive or body-powered prosthesis, while 38% accepted a powered hook or "pat a cake"4. When children transitioned to the myoelectric hands, acceptance increased to 58%4. The general acceptance rate of myoelectric prostheses in preschool children was 76%5.

First fitting before 2 years of age seems to be related to higher acceptance rates 6. 50% of children fitted at an age older than two years abandoned their prostheses compared to only 22% of children who had been fitted before the age of two years7. For the final type of prosthesis, children who wore an active prosthesis were more than twice as likely to wear it longer in life than children who wore a passive prosthesis8.

Additional factors that might increase prosthetic acceptance were: prosthetic cosmetic appearance, functionality in conducting specific tasks, appropriate training and positive parental influence9-11.

34% of tested children with trans-radial limb deficiency between the ages of 2-20 years (n=498) rejected their prosthesis1. The principal reasons for rejection of a prosthesis were lack of function (53% of 135 non-users), and lack of comfort (49% of non-users)1. Additional factors that might increase prosthetic rejection were user´s identity challenges, level of deficiency (children with higher levels of upper limb deficiency tend to wear their prosthesis longer), and negative parental influence9,10.

Discussion: The factors that drive prosthesis acceptance in children differ from those that are leading to the prosthesis rejection. Focusing on them might increase upper limb prosthetic acceptance and use later in life.

Theme: Clinical Prosthetics

Poster Title: Choosing a myoelectric hand and hardware that suits the unilateral amputee's functional requirements

Authors: Judith Davidson

Abstract: Aim of the Study
Enabling the amputee to choose his own multi-functional hand has been a project for the last 4 years.

Techniques Used
In NSW, the insurers need justification of the functional benefits of the multifunctional hand prior to its approval. It is difficult to be specific about the most appropriate hand without the use of a trial prosthesis.

Results
Each trial costs about $5,000 if an interim socket has to be fabricated but $1,000 if they already have a suitable socket. Every insurer has approved the interim socket and trial of the hand. They can see their way to approve $5,000 without high levels of justification but the cost of $100,000 requires oversite by the NSW governing body and is much more stringent).
The method of prosthetic control was identified accurately, the postures that were identified, the outcome from other trials if another hand has been used. The amputee also takes responsibility for their own decisions Manufacturers know that they have to be able to loan hand to make future sales.

Conclusions
There have been 3 partial hand, 8 trans-radial and 4 transhumeral amputees.

Patients dislike harnessing and prefer silicone liners for suspension. This is enabled with electrode holes cut in the liners.

One partial hand did not want the Idigits due to lack of durability.

One trans-radial patient was refused multifunctional hand but approved for a rigid grip hand (due to cost)

One partial hand is awaiting approval of the trial.

12 mutlifunctional hands have been approved.

Two out of 3 transhumeral subjects have chosen to have roll on silicon liners.

Theme: Clinical Prosthetics

Poster Title: Integration of Comfort and Control for UL Treatments

Authors: Erik Andres

Abstract: Introduction: According to a survey (Stark, 2013), the factors which significantly affect upper limb prosthetic acceptance, is amputation level, functional advantage, socket & harness comfort, and peer/family support.

In this presentation, the author is referring to the topics socket & harness comfort.

Since the inception of prosthetic devices usage by people with upper limb loss, the prosthetic socket design presents orthopedic technologist a challenging task. Especially because this connection- element between human body and prosthetic device must allow comfortable and secure use.

For myoelectric prosthesis, an absolutely secure fit and adhesion between skin and socket is required. Every slide produces malfunctions and insecurity in the myoelectric controls.

Easy donning and doffing of the device is also a very important factor for acceptance.

Methods: People were fitted with prosthetic devices and harnesses in an individual and modern style. In these fittings, silicone use is shown with new and unique applications and approaches.

Silicone is used, because of it's well known advantages for use in medical devices.*

Successful applications presented, show use in cases from the transradial through to bilateral shoulder disarticulation level. Some examples:

- Elbow-disarticulation prosthesis fitting with use of an inflatable air-bladder to increase fit through following contours
- TMR with use of an integrated air- bladder to increase electrode pressure on the skin for complex control schemes
- Localized use of silicone gel in a socket to provide high adhesion or to follow the contours of invaginated scars
- Adaptations to individual harnesses to increase comfort and for a unique force-distribution.

Results: The results presented show well accepted upper- limb sockets and harness prosthetic treatments, with outcomes showing better comfort and more long- term use of the prostheses. The applications shown will be readily usable in cases with and without myoelectric control and use available materials and techniques.

Disclosure: The author is a full-time employee of Ottobock.

Acknowledgements:The author thanks the members of the Department Upper Limb of Competence Center Headquarters Otto Bock/ Germany

* Bio- compatible/ Antiallergenic, High temperature-stability (-60 - +200°C), Different shore-hardness's are combinable, Unique hygienic characteristics, High adhesion, Inner-layer can be coated with silicone-gel, Durability, Highly flexible, Positive influence on scars

Theme: Clinical Prosthetics

Poster Title: The Use of Custom Silicone for a Sport-Specific Partial Hand Prosthesis: Design and 4 Month Follow-up

Authors: Kyle Sherk and Jack Uellendahl

Abstract: Prosthetic solutions for the pediatric partial hand remain custom in design and fabrication. This case study moves through the fitting and fabrication process of the prosthesis and follows the patient, AM, through 4 months of use. AM was born with a congenital limb difference of her 2nd-4th fingers of her left hand. Her right hand is normal. At age ten, she began gymnastics and came to enjoy the uneven bars. Her left hand limited her progression in the event. AM was fitted with her prosthesis in March 2016. Follow-ups continued through July 2016. This case study demonstrates that a functional, sport-specific prosthesis can be entirely of high consistency rubber (HCR) silicone.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Evaluation of hand function transporting fragile objects: the Virtual Eggs Test

Authors: Marco Controzzi, Francesco Clemente, Neri Pierotti, Michele Bacchereti and Christian Cipriani

Abstract: The evaluation of the hand function is of great importance in both clinical practice and research activities. Assessment tools are essential to provide the therapist or investigator with relevant and objective information concerning the patient status, the effectiveness of the treatment program and the assistive technology prescribed. This abstract presents the design and the administrative instructions of a new hand assessment test: the Virtual Eggs Test (VET), that resembles the task of transporting fragile objects. The test builds on investigations on pick and lift tasks, showing that humans exert on objects grip forces (GF) that are sufficient to prevent slips, and yet are not so excessive as to crush a fragile object. While grasping humans apply GF and load forces (LF) in coordination, which is disrupted when sensory information from the fingertips is lost. The VET replicates the box and blocks test except that breakable blocks are used instead of the standard wooden ones (Figure 1a). The performance is measured by the number of blocks transferred and percentage of blocks broken during 1 minute trials.

We designed two assessment instruments for this test that may be used depending on the performance that have to be recorded: the magnetic Virtual Egg (mVE), and the instrumented Virtual Egg (iVE). In the mVE (Figure 1b), empty blocks (40x40x40mm, ~80g) are equipped with a magnetic fuse which exploits the attraction force between two magnets to maintain a fixed distance between two opposite walls of the block. When a GF larger than the attraction force between the two magnets is exerted on the object, the walls collapse and the object "breaks". The iVE (Figure 1c) enriches the assessment power of the mVE by measuring the GF and LF. This allows to evaluate (i) the ability to modulate the GF and (ii) the rate of temporal GF-LF coordination. The iVE is a test-object (57×57×57mm; variable weight from ~180g up to 340g) equipped with two strain gauge-based force sensors, able to measure the GF. An additional sensor is placed on the base of the test object, acting as a stand able to measure the LF of the test-object when it is resting on it. If the subject generates a GF larger than the threshold, the instrumented object virtually breaks; this may be signalled to the subject through an acoustic signal, coloured light and/or short vibration. Data are recorded and transferred using a wireless protocol to the PC.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Kinematic insights from a novel gaze and movement metric for upper limb function: normative and prosthetic comparison

Authors: Aida Valevicius, Quinn Boser, Ewen Lavoie, Craig Chapman, Patrick M. Pilarski, Albert Vette and Jacqueline Hebert

Abstract: The evaluation of advanced upper limb prosthetic devices is limited since current outcome metrics may not be sensitive enough to detect compensatory movements and control strategies. We developed two functional tasks for device and performance assessment that are amenable to motion and eye tracking that mimic activities of daily living. The tasks incorporate elements of lateral motion, crossing the body's midline, accuracy, and risk.

Kinematic data from twenty healthy participants and one prosthetic user with a myoelectric and body-powered prosthesis were analyzed. The following degrees of freedom were included in the analysis: trunk flexion-extension, abduction-adduction, and axial rotation; shoulder flexion-extension, adduction-abduction, and internal-external rotation; elbow flexion-extension and pronation-supination; and wrist flexion-extension and ulnar-radial deviation. The range of motion (ROM) was extracted from joint angle trajectories for each examined degree of freedom. End-effector metrics included time to task completion, maximum hand velocity, time and percent to peak velocity, and number of movement units.

Joint kinematics and end-effector metrics where substantially different between normative and prosthetic performance. In comparison to normative performance, the prosthetic user exhibited increased ROM in trunk flexion-extension and shoulder adduction-abduction for both prosthetic devices and tasks. This suggests a compensation for lack of elbow and wrist joint motion by relying more on trunk and shoulder motion to complete the tasks successfully. Despite longer movement times, when using his myoelectric prosthesis, the prosthetic user's ROM was closer to normative performance when compared to his body powered prosthesis. Velocity peaks occurred earlier during reach and grasp movements, indicating a prolonged deceleration phase or a change in movement strategy.

These preliminary results suggest that a range of quantitative information can be extracted from a kinematic analysis of upper body movements. Movement strategies that trend towards normative functional motion could have the potential to reduce the risks of overuse injuries in prosthetic users, given that repetitive movement outside of the normal ranges of function put individuals at greater risk (Kidd, McCoy, & Steenbergen, 2000). In fact, Jones & Davidson reported that 50% of individuals with upper limb amputations reported suffering from an overuse injury (Jones & Davidson, 1999). The proposed motion capture protocol allows us to assess differences between normative and prosthetic performance, but also between different prosthetic technologies. Like common gait assessment practices, the norms can be used as a benchmark for assessing upper limb impairments, advanced technologies, and performance improvements over time, which will be the focus of future work.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Two-DoF, Dynamic EMG-Based Estimation of Hand-Wrist Forces with a Minimum Number of Electrodes

Authors: Chenyun Dai, Ziling Zhu, Carlos Martinez Luna, Thane R. Hunt, Todd R. Farrell and Edward A. Clancy

Abstract: Introduction: Commercial hand-wrist prostheses realize partial function for amputees via electromyogram (EMG) control derived from remnant muscles. Most EMG-based prostheses provide only one degree of freedom (DoF) of control at a time. Our study explored the minimum number of electrodes required for 2-DoF simultaneous hand-wrist force estimation.

Methods: Nine able-bodied subjects participated. Sixteen conventional bipolar EMG electrodes were equally spaced around the proximal forearm. The hand was secured to a load cell measuring open-close (Opn-Cls) force; the wrist was fixed to a 3-DoF load cell measuring extension-flexion (Ext-Flx), radial-ulnar deviation (Rad-Uln) or pronation-supination (Pro-Sup) force. Subjects performed constant-posture, dynamic force tracking of a random computer target (0.75 Hz bandwidth). One-DoF trials tested the four forces separately. Two-DoF trials tested hand Opn-Cls paired with one wrist force. Linear least squares regression related EMG to force. Backward stepwise selection reduced the number of electrodes from 16 to 1.

Results: One-DoF models: Two-way RANOVA found an effect due to number of electrodes [$F(1.8, 14.7) = 99$, $p_{GG}<0.001$], but not DoF [$F(3, 24) = 0.54$, $p=0.66$]. Post hoc paired t-tests (Bonferroni corrected) only found error higher when comparing 1 electrode to more than 1 ($p\leq0.001$); and 13 electrodes to 10 ($p=0.006$; argued to be a false positive). The errors for the four respective forces, Opn-Cls, Ext-Flx, Rad-Uln and Pro-Sup, were 8.8 ± 3.3, 8.3 ± 2.0, 9.0 ± 1.6 and 8.7 ± 2.2 %MVC.

Two-DoF models trained from 1- and 2-DoF trials, tested on 2-DoF trials: RANOVA main effect of number of electrodes was significant [$F(1.6, 12.9) = 99$, $p_{GG}<1e-6$], but DoF was not [$F(2, 16) = 0.07$, $p=0.9$]. Post hoc analysis of electrodes found 1 electrode exhibited higher error than more than 1 ($p<0.003$), 2 electrodes higher than more than 3 ($p<0.003$), 3 electrodes higher than more than 5 ($p<0.02$), 4 electrodes higher than more than 5 ($p<0.03$), and 5 electrodes higher than 6 or 10–13 ($p<0.05$). With four electrodes, the 2-DoF errors for Ext-Flx, Rad-Uln and Pro-Sup (each paired with hand Opn-Cls) were 9.2 ± 2.0, 9.2 ± 1.6 and 9.2 ± 1.4 %MVC, respectively.

Conclusion: While low errors in a lab study do not necessarily reflect improved performance in a prosthesis, such studies are useful to refine algorithms. Our 1- and 2-DoF results showed similar errors. As few as four conventional electrodes provided good performance. Testing in a hand-wrist prosthesis is an appropriate next step.

Funding: NIH award R43HD076519.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Descriptive outcome metrics of sensorized upper limb performance using optimal foraging theory

Authors: Dylan Beckler, Zachary Thumser and Paul Marasco

Abstract: Modern advancements of upper-limb prosthetic technologies have not been accompanied by advancements in appropriate metrics for assessing the functionality of these technologies. In particular, many of the currently accepted functional metrics of performance for upper-limb prostheses put little or no emphasis on the role of sensory feedback modalities in the prosthesis control loop. We developed a functional metric of Prosthesis Efficiency and Profitability (PEP) which incorporates tactile and proprioceptive elements into a simple motor task. PEP uses Optimal Foraging Theory (OFT), which describes decision making in biological systems based on time versus prey-value tradeoffs, as a platform to evaluate the compensatory interactions between motor command and sensory feedback in a prosthesis control loop. PEP participants are instructed to discriminate between objects of different stiffnesses in a timed search and acquisition task. The primary outcome measures: efficiency and profitability, weigh the accuracy of stiffness discrimination against speed. Additionally, Bayesian statistics are used to determine the frequency of false positive and false negative errors made by the participant during the test to further describe the tradeoff between motor command and sensory feedback. We have found that the PEP test is sensitive to the effects of touch and movement feedback and highlights strategy switches and changes in performance for different devices and feedback settings. We observed subjects switching from relying on motor command to relying on sensory feedback when the feedback was turned on. When feedback was absent, participants on average had lower accuracy but compensated by engaging with objects more quickly. Whereas when feedback was present, participants tended to spend more time engaged with each object but got more objects correct. Additionally, an ability to discriminate stiffnesses beyond chance was demonstrated in prostheses users equipped with touch and movement feedback when the sensory feedback was switched on. The PEP test may provide a general framework for evaluating different sensory modalities; the objects of different stiffnesses may be replaced with objects possessing the property of interest, changing the focus of the test without altering the analysis or interpretation of outcome metrics.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Influence of a transradial amputation on neuromuscular control of forearm muscles

Authors: Morten Bak Kristoffersen, Andreas Franzke, Alessio Murgia, Raoul Bongers and Corry van der Sluis

Abstract: Following an upper-limb amputation the muscles and tendons in the amputation stump are often rearranged by a surgical procedure. One of the purposes of this rearrangement is to shape the stump as to optimally support the prosthesis socket, and to create good control sites for a myoelectric prosthesis using direct control. For the transradial level the main wrist flexors and extensors are used for the latter purpose and the remaining muscles are mainly used for reshaping the stump. This is an interesting phenomenon from a motor control perspective and questions arise to how the control strategy of the neuromotor system changes after amputation when muscles and other tissues are rearranged and subsequently degenerate. Moreover, the feedback loop is heavily altered due to absence of a moving limb. This also appears to have an effect on the electromyogram (EMG) as demonstrated in several studies in which motion intent was classified using features of the EMG measured at the forearm. When comparing classification accuracy between able-bodied subjects and amputee subjects the accuracy was lower for the amputees. However, the relative accuracy between able-bodied participants and amputees is fairly consistent among a range of classification algorithms. Therefore, many studies recruit able-bodied subjects and extrapolate their results to the amputee population.

In this study we aim to investigate how transradial amputation influences the EMG in an effort to improve the transferability of results from able-bodied participants to amputee users. In our study protocol, we simultaneously measure the EMG at the forearm of both the unaffected and the affected side of transradial amputees. Participants will perform bimanual (phantom) movements in two different conditions. In the 'restricted-hand condition', the hand of the able side is restricted by a brace so the movement contractions become isometric. In the 'free-hand condition', the hand of the able side is not restricted. The purpose of restricting the able hand is to simulate the loss of hand movements while contracting wrist muscles and determine how this influences the EMG. We hypothesize that the EMG measured at the able-side in the 'restricted-hand condition' is more similar to the EMG at the affected side than it is in the 'free-hand condition'. To quantify this, we use a pattern-recognition algorithm to classify the motion intent from both sides and analyse the resulting classification clusters using the separability index, repeatability index and the semi-principal axes as described in the literature.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: A Self-Grasping Hand Prosthesis

Authors: Gerwin Smit, Bartjan Maat, Dick Plettenburg and Paul Breedveld

Abstract: Background: This study presents an innovative approach for passive adjustable hand prostheses. Around a third of the upper limb amputees uses a passive prosthetic device, which can be a prosthetic hand or tool. In literature there has been very little attention for improvement of the function of passive adjustable (PA) hand prostheses.

Goal: The goal of our study was to design a next generation adjustable prosthetic hand. This prosthetic hand must be able to grasp objects without the help of the sound hand, and without the need of a harness or batteries.

Methods: An analysis of PA prostheses and relevant prosthetic characteristics was performed. We identified design requirements for a new and better PA prosthetic hand. The design of this new PA prosthesis mainly focused on two features; the grasping mechanism and the locking mechanism. For both features a function analysis was performed. Different working principles were designed and tested. A final prototype was designed, built and evaluated.

Results: We designed an innovative passive prosthetic hand, the Delft Auto-grasping Hand (DAH). This hand has articulating fingers and can perform the hook grip, power grip and pinch grip. The gripping function is controlled indirectly by pushing an object to the hand, or directly by pushing the prosthetic thumb against a fixed object. The grip force is proportional to the applied push force. By releasing the push force, the grip force is locked and the object is being held. In order to release the object, a button has to be pushed after which the object can be released by pushing the object slightly into the hand. The DAH has a mass of only 130 grams. In an evaluation the DAH was compared with a conventional PA prosthesis. Activities were performed 11 % faster and required less user effort with the DAH. During the activities, the grasping function of the DAH was used 54% more often.

Conclusion: This study presents a next generation passive adjustable prosthetic hand, the Delft Auto-grasping Hand (DAH). The hand can grasp objects without the help of the sound hand. The DAH is the first PA prosthetic hand which has articulating fingers and can perform the hook grip, power grip and pinch grip. The evaluation showed that the DAH has a good grasping functionality and is easy to control. This innovative prosthetic hand offers an attractive alternative to current passive prosthesis, and possibly even to active prostheses.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Service Members and Veterans with Transhumeral Osseointegration: Initial Rehabilitation Experiences from the DoD OI Program at WRNMMC

Authors: Annemarie Orr, Michelle Nordstrom, Mark Beachler, Josef Butkus, Brad Hendershot, Barri Schnall, David Laufer, Stanley Breuer, Paul Pasquina, Benjamin Potter, Jonathan Forsberg and Christopher Dearth

Abstract: Background: Since September 11, 2001, the Armed forces sustained a total of 1,706 combat amputations in which 296 had upper extremity involvement. In 2010 it was identified that 22% of the Operation Iraqi Freedom/Operation Enduring Freedom Veterans with unilateral upper-limb amputations have completely abandoned their prosthetic devices and the percent of Vietnam Veterans who abandoned their prosthesis was 30%. Prosthetic abandonment is due to many factors including pain, weight, skin breakdown, and lack of consistent function.

Osseointegration has been performed internationally for facial injuries, hearing aids, finger joints, and limb prostheses over the last two decades. Initial procedures in United States were performed for lower limb amputations beginning in 2015 with the first FDA approved devices becoming available in 2016.

Walter Reed National Military Medical Center is working to reduce the rate of abandonment through the implementation with Osseointegration (OI); using a direct skeletal attachment technique developed by P-I Brånemark from Gothenberg, Sweden called Osseointegrated Prostheses for the Rehabilitation of Amputees (O.P.R.A.). Initial enrollees in the clinical trial for transhumeral amputees have had long standing issues with prosthetic functionality leading to abandonment or limited use, but desire to use their prosthetic device. This abstract is intended to describe the rehabilitation protocol, rehabilitation timeline, and lessons learned from the first three upper limb OI participants.

Methods: The rehabilitation protocol between the two surgeries includes wound care, range of motion (ROM), and strengthening with a clinical ROM evaluation conducted every two to three weeks. The goal between the first and second surgeries is to maintain ROM and strength. Three to four weeks after the second surgery a training prosthesis is incorporated into the treatment plan to gradually increase weight tolerance. Assessments are performed pre and post-operatively over a 24 month timeframe. Evaluations include Goniometric and Biomechanical ROM measurements, ACMC, UNB, Box & Blocks, and pinch pins.

Results: Preliminary results of the first three participants self-report using the Visual Analog Pain Scale, DASH, and PROMIS Questionnaires minimal discomfort in between surgeries. ROM and strength were regained following their home exercise program (HEP). No clinical setbacks (infection, surgical complications, or excessive pain) impacted the rehabilitation progress of the initial participants. All three reverted back to their previous prosthetic use between Stage 1 and Stage 2 surgeries.

Conclusion: The OI procedure has given patients the opportunity to explore new avenues, improve prosthetic functioning, and quality of life.

Theme: Sensory Feedback

Poster Title: Measuring User Experience of A Sensory Enabled Upper Limb Prosthesis

Authors: Linda Resnik, Emily Graczyk and Dustin Tyler

Abstract: Background: New technologies that restore sensory feedback to upper limb prosthesis users have the potential to greatly improve quality of life. One such technology is the sensory restoration systems (SRS) developed at Case Western Reserve University. Measuring the impact of SRS is challenging, given that existing measures do not quantify likely psychological impacts of SRS.

Purpose: To describe the development of a multi-dimensional subjective experience scale that is responsive to change associated with use of an SRS.

Methods: Content development: Measure content was identified through informal conversations with two subjects implanted with an SRS, discussion with subject matter experts and literature review. Preliminary item banks were drafted and reviewed by measurement workgroup members. Items were refined based on feedback. Subscales were created for: self-efficacy of prosthesis use, prosthesis embodiment, body image, prosthesis efficiency and social touch.

Patient Experience Measure: Items are graded using a 5 point Likert Scale (strongly disagree to strongly agree). The self-efficacy subscale asks subjects to rate confidence using the prosthesis to complete 7 items which are typically challenging for prosthesis users. The Embodiment subscale consists of 8 items that ask about prosthetic embodiment (e.g. the prosthesis is a part of me) The 9-item Body Image subscale asks about impact of the prosthesis on self-image (e.g. when I remove my prosthesis I feel more confident). The 3-item Prosthesis Efficiency scale includes items relating to speed and focus required to use the prosthesis. Finally, the social touch subscale consists of 11 items pertaining to prosthesis use in social interactions.

Data collection: Two subjects with implanted SRS participated in a home study. During the intervention stage, each wore an experimental hand system with embedded sensors and received nerve stimulation. During the Pre-test and Post-test stages, subjects wore the experimental hand system, without stimulation. At the end of each stage, subjects completed the Patient Experience Scale.

Data analysis: Item scores for each subscale were averaged. Descriptive analyses were conducted by subject and stage.

Results: Scores for self-efficacy, embodiment, efficiency and social touch subscales were higher for the sensory stimulation stage for both subjects. Scores for body image were highest for subject 1 at post-test and highest for subject 2 during sensory stimulation.

Conclusions/Implications Findings provide preliminary evidence of the validity and responsiveness of the Patient Experience Scale, a unique measure designed to quantify impact of prosthetic sensory restoration. Data collection in additional subjects will enable examination of scale internal consistency.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Real-time classification of five grip patterns with only two sensors

Authors: Agamemnon Krasoulis, Kianoush Nazarpour and Sethu Vijayakumar

Abstract: Current state-of-the-art prosthetic hand systems utilize electromyography (EMG) signals recorded from the user's residual muscles to decipher movement intention and control the prosthesis. To achieve a high level of decoding accuracy and robustness, a large number of EMG sensors is typically required. This requirement can both limit the functionality of the device from the user's perspective, as well as increase the power/computational requirements of the system. In this study, we propose a full framework for efficient and robust pattern recognition-based prosthetic hand control by using a single pair of EMG/inertial measurement (IM) sensors. Our proposed framework can be summarised as follows: 1) identify the optimal sensor location during an initial screening session by using a standard sequential forward selection algorithm; 2) deploy a regularized version of discriminant analysis classification which we have found that greatly outperforms linear discriminant analysis (LDA) when the input feature dimensionality is small; 3) adopt a novel classification rejection algorithm to minimize the controller's false positive rate (FPR). We assessed the performance of our proposed framework by conducting a real-time pick-and-place experiment with twelve able-bodied and two trans-radial amputee subjects Five different hand grips were included in our experiments: power/cylindrical, lateral/key, tripod, index pointer, and hand open. We found that after a few trials, participants were able to achieve robust prosthetic control performance (95% and 85% completion rates for able-bodied and amputee subjects, respectively). Furthermore, completion times were comparable to our previous work, where a larger number of sensors were used (4-6). This study provides a proof-of-principle for efficient pattern recognition-based prosthetic hand control with existing two-site EMG clinical systems.

Theme: Upper Limb Prosthesis Device Design

Poster Title: RTM-PDCP linkage platform multi-modal sensor control of a powered 2-DOF wrist and hand

Authors: Masaki Shibuya, Kengo Ohnishi and Isamu Kajitani

Abstract: Highly functional multi-DOF upper limb prostheses are available to the users, though problems remain on the control strategies' operation load. We proposed Multimodal Sensor Control, MSC, which integrates myoelectric signal and forearm posture signal to operate the prosthetic hand and wrist. Experiments comparing MSC and locked-wrist myoelectric control showed that compensatory shoulder motion can be reduced with MSC, yet only on specific conditions.

To augment the MSC to variety of daily activities with least operating burden, we propose to combine environmental information to the motion signal, e.g. myoelectric and forearm posture, since hand operation is selected by the relativity of the grasping object posture and hand orientation. The key is the network for streaming the environmental information to the prosthesis controller. A robotized room for comprehensive support environment for the physically handicapped is an expedient and RT-Middleware, RTM, has a proven strategy. Prosthetic Device Communication Protocol (PDCP) is the best test bed for the prosthetic control, and therefore, the objective of this project is to develop and verify the availability of MSC using environmental information with RTM-PDCP linkage platform. As a proof-of-concept model, wearable tag reader was implemented to demonstrate the operation based on the relativity of the hand and environment. By mounting RFID on the grasping target's surface, tag reader on the hand and an inclination sensor to the working table, the information of the tag ID, inclination angle of the object, approaching motion signal of inertia measurement unit and trigger of the myoelectric signals are combined to presume the grasping direction of the target object and switch the servo control mode and drives the 2 wrist motors to maintain the wrist angle to while grasping the object.

The operation load applying the MSC was verified by conducting experiment of 48 trials. A powered wrist and hand was assembled and donned on the right forearm of 4 non-amputees subjects. Six tasks were selected from the therapeutic battery, Simple Test for Evaluating hand Function (STEF), for evaluation. The operating forearm posture angles and work times of the trial with MSC and conventional myoelectric control were measured. The average work time of MSC was larger but not statistically significant, while the average forearm posture angle range was significantly smaller ($p<0.05$). These results of downgraded forearm posture angle range without prolonged operation time demonstrates that the MSC using environmental information can be operated on RTM-PDCP linkage platform and suppresses compensatory motion.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Pattern Recognition Myoelectric Control Calibration Quality Feedback Tool to Increase Function

Authors: Frank Cummins, Nathan Brantly, Blair Lock, Aimee Feuser and Levi Hargrove

Abstract: Pattern recognition control for upper-limb myoelectric prostheses is growing in clinical acceptance. Furthermore, powered prostheses are becoming increasingly complex, especially with the growing popularity of multi-articulating hands [1]. With a larger available motion set, requiring a larger number of patterns of muscle activity, complications can arise. Calibration feedback to rate the ability to control each available motion and provide tips for subsequent recalibration is highly beneficial in these cases. Here, a novel algorithm for determining calibration quality is presented.

Theme: Occupational Therapy & Outcome Measures

Poster Title: The Control Bottleneck Index: a novel outcome metric providing generalizable and actionable assessment of upper-limb prosthetic systems

Authors: Dan Blustein, Satinder Gill and Jon Sensinger

Abstract: Assessment tools for upper limb prostheses lack generalizability and provide little actionable information to improve outcomes. We have developed the Control Bottleneck Index (CBI), a new outcome measure driven by a computational motor control framework that can provide useful and actionable information regarding system performance. The CBI uses an existing hierarchical Kalman filter model (Blustein & Sensinger 2016, Johnson et al. 2016, Berniker & Kording 2008) to predict system parameters including sensory feedback uncertainty, controller uncertainty, and internal model uncertainty based on human psychophysics results. The CBI tasks include a baseline grasping task, a movement matching task without feedback and a two-alternative forced choice task to determine the just noticeable difference of a perturbation. Here we present this human movement assessment tool and demonstrate its responsiveness to changes in system parameters. The CBI is not task specific but we describe an implementation using a time-constrained grasping task in the Multi-Joint dynamics with Contact (MuJoCo) physics engine with endpoint visual feedback and EMG control (Todorov et al. 2012). We show that when sensory noise and control noise are experimentally adjusted, the CBI can predict changes in the expected underlying motor control model parameters. By inversely calculating model parameters using experimental results, this assessment framework can determine the relative levels of uncertainty of different system components in a human controlling a prosthesis. The results of the CBI can directly inform clinical improvements. For example, if a human performer exhibits a high level of sensory feedback uncertainty, then clinicians can direct improvements to the feedback systems on the prosthesis. The CBI represents a new assessment tool that provides generalizable and actionable information for clinicians working to improve upper limb prosthetic systems.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Channel Selection of Neural and Electromyographic Signals for Decoding of Motor Intent

Authors: Jacob Nieveen, David Warren, Suzanne Wendelken, Tyler Davis, David Kluger, David Page, Jake George, Christopher Duncan, Douglas Hutchinson, V John Mathews and Gregory Clark

Abstract: The ability to perform multiple degree of freedom (DOF) proportional control has distinct advantages when applied to next-generation prosthetic hands with individuated finger and wrist control. Regression-based methods provide simultaneously multi-DOF control and can perform untrained hand grasps (Clark et al., MEC17). Such methods use multiple feature channels per DOF but increasing channel count can diminish performance and increase the computational complexity. Ideally, one wants to use the fewest channels that provide the best performance. Here we report a comparison of channel selection methods and recommend a forward stepwise selection method with Gram-Schmidt orthogonalization applied between steps. This approach uses the fewest channels that results in equivalent or no worse performance than other methods investigated, and it is our current standard method for real-time testing.

We used data from one volunteer with transradial amputation to compare the performance of four channel selection methods: channels that correlate with movements (CORR); Gram-Schmidt orthogonalization, forward selection (GS); Least Angle Regression (LARS); and Mutual Information (MI). The subject was chronically implanted with a 32-electrode intramuscular electromyogram (EMG) array in residual forearm muscles (Ripple, LLC) and two Utah Slanted Electrode Arrays (USEAs, Blackrock Microsystems), one in each of the median and ulnar nerves. From these sources, the Mean Absolute Value of 32 single-ended and 496 differential EMG channels and neural firing rate of 192 USEA channels were calculated at 30 Hz (720 total channels). All analyses were performed offline using six online training data sets. From these data, channels were selected and a decoder was trained with subsets of single DOF movements across 6 DOFs and tested with distinct subsets. Performance was quantified by the root mean squared error (RMSE) normalized to each joint's range of motion.

All methods examined performed to similar levels in testing datasets, achieving a minimum mean RMSE of 0.11+/-0.0032 (mean+/-SEM over all DOF and datasets, no significance difference between methods). However, the number of channels necessary to achieve that best mean result differed among channel selection methods with GS requiring the fewest channels (55) and CORR requiring the most (122). MI failed to find an optimal set from 720 channels within reasonable computation time. On an Intel i7, the processing time necessary to select channels ranged from 240 milliseconds (CORR) to 52 minutes (MI, while selecting from 80 EMG channels), with GS taking 24 seconds. From these results, we recommend using the Gram-Schmidt orthogonalization, forward-selection method to choose feature channels.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: The PSYONIC Compliant, Sensorized Prosthetic Hand

Authors: Aadeel Akhtar, Kyung Yun Choi, Jesse Cornman and Wenjun Sun

Abstract: We present a compliant, sensorized prosthetic hand that enables both motor control and sensory feedback for people with upper limb amputations. The hand has six powered degrees of freedom, corresponding to flexion/extension in all five fingers and thumb rotation. The dimensions of the hand are at 50th percentile female anthropometry.

The fingers of the prosthesis were designed to be compliant and can withstand sharp impact forces applied from anterior, posterior, and lateral directions. We achieve compliance in the distal and proximal interphalangeal joints through the use of a flexible bone inside of a silicone outer structure. Worm gears provide non-backdrivability to decrease power consumption when gripping objects with constant high torque. The worm gears and motors are protected from environmental shock since the compliant joints prevent damage to the gears.

Pressure sensing is achieved through a flexible printed circuit board that houses three pressure sensors and can wrap around the proximal interphalangeal joint of the finger. The finger is able to detect pressure through the use of three MPL3115A2 barometric pressure sensors (Freescale, Austin, TX) mounted on the flexible PCB. We cast the sensors in silicone (Dragon Skin 20, Smooth-On, Macungie, PA) to turn them into sensitive contact pressure sensors. The three sensors are placed over common areas of contact (fingertip, finger pad, and lateral finger) when making power and lateral grasps. The pressure readings can easily be mapped to sensations provided through vibrotactile, electrotactile, or other sensory feedback interfaces.

The entire hand can be built for less than $1000. This low cost makes research and development of sensorimotor prosthetic hands more accessible to researchers worldwide, while also being affordable for people with amputations in developing nations. Furthermore, the hand can be easily integrated into standard sockets, facilitating long-term use and testing of sensorimotor capabilities.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Giving Them a Hand: Wearing a Myoelectric Elbow-Wrist-Hand Orthosis Reduces Upper Extremity Impairment in Chronic Stroke

Authors: Heather Peters, Stephen Page and Andrew Persch

Abstract: Objective: To determine the effect of a portable, myoelectric elbow-wrist-hand orthosis (MEWHO) on paretic upper extremity (UE) impairment in chronic, stable, moderately impaired stroke survivors.

Design: Observational cohort study.

Setting: Outpatient rehabilitation clinic.

Participants: Stroke survivors exhibiting chronic, moderate, UE hemiparesis (N=18).

Interventions: Subjects were administered a battery of outcome measures testing UE impairment, functional performance and gross manual dexterity. They then donned a fabricated MEWHO and were again tested on the same battery of measures while wearing the device.

Main Outcome Measures: Outcome measures included the UE section of the Fugl-Meyer Impairment Scale (UEFM), a battery of functional tasks and the Box and Block (BB) test.

Results: Subjects exhibited significantly reduced UE impairment while wearing the MEWHO (FM: $t=8.56$, $P<.0001$) and increased quality in performing all functional tasks while wearing the MEWHO, with 3 subtasks showing significant increases (feeding [grasp]: $z=2.251$, $P=.024$; feeding [elbow]: $z=2.966$, $P=.003$; drinking [grasp]: $z=3.187$, $P=.001$). Additionally, subjects showed significant decreases in time taken to grasp a cup ($z=1.286$, $P=.016$) and increased gross manual dexterity while wearing a MEWHO (BB test: $z=3.42$, $P<.001$).

Conclusions: Results suggest that UE impairment is significantly and immediately reduced when donning a MEWHO, and these changes exceeded the UEFM's clinically important difference threshold. Further, utilization of a MEWHO significantly increased gross manual dexterity and performance of certain functional tasks.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Deriving Proportional Control for Pattern Recognition-Based Force Myography

Authors: Alex Belyea, Kevin Englehart and Erik Scheme

Abstract: Force myography (FMG) has been proposed as an alternative to electromyography (EMG) for controlling a powered prosthesis. Previous research has varied in sensor type and configuration, and in control signal processing approaches. Some groups have used low numbers of sensors, while others have included high density grids (HD-FMG). These HD-FMG systems have been shown to reach offline classification accuracies as high as 99.7% for up to 8 classes of motion. As has been shown, however, high offline classification accuracy does not necessarily ensure a high level of prosthetic device usability. One large factor that contributes to the usability of a device, beyond its classification accuracy, is the use of proportional control.

As a precursor to an ongoing real time usability study, this work focussed on developing a proportional control scheme for use with pattern recognition based HD-FMG. Initial pilot work employed the mean of all channel outputs, as has long been used for proportional control in pattern recognition based EMG systems. It was found, however, that the HD-FMG signal did not monotonically increase with increasing effort. This is understandable given the subtleties of muscle synergies and their resulting patterns of mechanical deformation during graded contraction. Here, a class-specific proportional control signal was computed using a regression model trained to map FMG levels to the position of a prompted target.

In order to evaluate the performance of these approaches, HD-FMG and load cell data were collected from 14 participants as they matched their effort to a visual target prompt. Subjects were prompted by a visual position prompt to elicit 4 different active classes of wrist motion with their wrist constrained in a load cell device. From these data, the two proportional control were computed, and compared to both the load-cell value and the position of the visual prompt.

Overall, the average classification accuracy between the 5 motions was found to be 99.9%. The mean value proportional control approach yielded an R2 coefficient of determination of 0.453 with the visual prompt target. The regression based mapping approach resulted in an R2 coefficient of determination of 0.875.

This work represents a step towards real-time usability assessment of a HD-FMG based control scheme. These results suggest that a class-specific regression-based proportional control scheme may be effective for use as part of a pattern recognition based system.

Poster Session B

Day 2: Wednesday, August 16, 2:45PM-3:45PM

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Poster Session B – Abstracts

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: System group dynamics and their effect on upper limb innovation in O & P

Authors: Gerald Stark

Abstract: Since any new innovation inherently comes with a higher degree of uncertainty and risk, the group or individual must deal with the anxiety created by this innovative behavior. This may be especially true in Upper Limb prosthetics where contextual stress is heightened.

This study was a non-experimental, associational, design using an electronic survey comparing emotional differentiation, as measured by the Workplace Differentiation Inventory (WDI), and technology readiness as measured by the Technology Readiness Index 2.0 (TRI-2.0). The intent of the study was to examine the potential relationships between the WDI and TRI-2.0 as well as the subattributes of both instruments. The analysis was done to find if any relationships exist between the WDI and TRI-2.0 with respect to the demographic attributes of gender (G), years of experience (EXP), professional certification (CERT), technology self-assessment (TSA), number of high-tech patients per year (HTP), number of external linkages (EXLK), number of internal linkages (INLK), and professional affiliation (AFF).

The survey, which included the eight demographic questions as well as the WDI and TRI 2.0, was made available with a link and invitation on the OANDP-L list server. The survey was posted on Qualtrics from August 18, 2015 until August 31, 2015, and had n = 148 respondents. Examination of the relationships using two-tailed Person's correlations and regression a moderately strong predictive relationship between the WDI and the TRI-2.0. A very strong predictive relationship was found between Technology Optimism with Emotional Cut-off and Emotional Reactivity. Technology Optimism and Emotional Reactivity alone shared a strong predictive relationship. Conversely, the WDI had very strong predictive relationship with Technology Optimism, Technology Innovativeness and Technology Insecurity with Technology Optimism contributing a majority of the effect.

This study has also shown that Technology Optimism, Technology Innovativeness, and Technology Insecurity had a very strong significant predictive relationship on Workplace Differentiation, specifically Emotional Reactivity, with Technology Optimism being the most substantial. Another key result was that Gender, Technology Self-Assessment, Certification Level, Years of Experience, and Office Affiliation had little or no effect on the measures of differentiation or technology readiness. The implication is that continual introduction of new concepts and technology would be a strong predictor of a less emotionally reactive and thoughtful group for change represented by technologic and reimbursement advancements.

Theme: Clinical Prosthetics

Poster Title: Factors that influence acceptance and rejection of an upper limb prosthesis: A review of the literature.

Authors: Andreas Kannenberg

Abstract: Introduction: Clinicians and health insurances are well aware of the fact that many patients with upper limb (UL) amputations reject their prosthesis in the mid- to long run. Factors that influence acceptance and rejection of an UL prosthesis are much less understood. If such factors and their impact were known, they could be leveraged to improve the acceptance of UL prostheses and the function and quality of life of persons with UL amputations.

Method: A search of the scientific literature was performed in the Medline, Embase, CINAHL, OTseeker, and PEDro databases as well as in the online library of the Journal of Prosthetics & Orthotics. Search terms were related to UL amputations and prosthetics, acceptance, use, rejection and abandonment of UL prosthesis. Identified references were evaluated for pertinence to the subject and analyzed.

Results: Malone et al. suggested a "golden window" of 30 days after the amputation for the fitting of an (interim) UL prosthesis for occupational therapy. They found that all patients who received a prosthesis within this "golden window" were able to return to work, whereas only 15% of patients fitted after more than 30 days did so. In addition, patients fitted within the "golden window" did not present any striking preference for body-powered or myoelectric prostheses, whereas patients who were fitted later almost exclusively preferred myoelectric prostheses. Another study found that definitive prosthesis fitting within 6 months of the amputation or 2 years after birth in congenital deformities increased the likelihood of prosthesis acceptance (odds ratio) by factor 16. The second biggest variable was the involvement of the patient in the selection of the type of prosthesis. Intense patient involvement increased the likelihood of acceptance by factor 8. Also, patients with transradial amputations were more likely to accept a prosthesis than patients with more distal or proximal levels of limb absence.

Discussion: Patients should be fitted a prosthesis for occupational therapy as soon as medically possible, ideally within 30 days after the amputation to prevent them from learning to manage their everyday lives with their sound hand alone. Definitive prosthesis fitting should occur within 6 months of the amputation or 2 years of birth in case of congenital deformities for the same reason. Also, patients should be intensely involved in the selection of prosthesis type as they are then 8-times more likely to accept their UL prosthesis than those not involved in decision making.

Theme: Other

Poster Title: A Focus on the Patient Experience: Advanced Upper Limb Prosthetic Restoration vs. Hand Transplantation and Toe-to-Hand Transfers

Authors: Diane Atkins

Abstract: Introduction: Dramatic advances have been made in electric multi-articulating hands, hand transplantation and reconstructive hand surgery during the last several years. When debating the best solution, it is critically important to enable individuals with limb loss to be able to make an informed decision with respect to aspects of: time from procedure to "function", costs, amount of therapy required, medications, potential complications, sensation, pinch and grasp, functional outcomes, as well as the appearance of the hand. The purpose of this study is to present the experience of individuals with bilateral hand amputations, their perception of disability as well as their function following these interventions.

Methods:The subject population included 3 study groups- 3 bilateral transradial users of electric multi-articulating hands, 4 bilateral hand transplant patients and 1 bilateral multiple toe-to-hand transfer patient. Each individual was evaluated with the Southampton Hand Assessment Procedure (SHAP) and the Disabilities of Arm, Shoulder and Hand (DASH).

Results: The Index of Function, as defined by the Southampton Hand Assessment Procedure (SHAP), demonstrated surprisingly similar results among bilateral prosthetic users, bilateral recipients of hand transplantation, and the bilateral toe-to-hand transfer. When comparing the results of the Disabilities of Arm, Shoulder and Hand (DASH), bilateral transradial users of electric multi-articulating hands scored a lower perception of disability (mean=39.83) when compared to individuals who had undergone hand transplant surgery (mean=53.25). The DASH score of the individual who had undergone bilateral toe-to-hand transfers was the lowest at 27.

Conclusion: Although the subject sample is small, this study sets the stage for further investigation as advances and options become available for the individual who has lost both hands, so that a prospective patient can compare not only the objective functional outcomes, but also the subjective experience as well.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: Review of the current literature on the clinical benefits of multiarticulating prosthetic hands.

Authors: Andrea Giovanni Cutti and Andreas Kannenberg

Abstract: Introduction: For more than 40 years, myoeletric prosthetic hands have only allowed for the tripod opposition grip. In the past 10 years, multiarticulating hands offering up to 36 different grips have become available and popular among patients and clinicians (1). Therefore, a review of the literature on the clinical benefits of multiarticulating hands appears warranted.

Method: Scientific literature was searched in the Medline, Embase, CINAHL, OTseeker, and PEDro as well as in the online library of the Journal of Prosthetics & Orthotics. Search terms were related to multiarticulating prosthetic hands and their clinical benefits. Identified references were evaluated for pertinence to the subject and then analyzed.

Results: Only three publications, one case study (2) and two clinical studies (3, 4) on the clinical benefits of multiarticulating hands could be identified. The case study (2) was conducted with the iLimb in a 45-year old man with a wrist disarticulation and concluded that it had only limited additional functionality compared to the DMC plus hand (2). The two clinical studies were both conducted with the Michelangelo hand. A survey with the OPUS-UEFS for perceived function in 16 transradial amputees demonstrated improved ease of performing activities of daily living (ADL) and increased active use of the multiarticulating as compared to standard myoelectric hands (3). A study with 6 transradial amputees assessing performance-based outcomes measures found significant improvements in the SHAP, the Box and Blocks test, and the Minnesota Manual Dexterity Test (4). Patient interviews after 6 months revealed enhanced perceived functionality and the perception of Michelangelo "as a real hand", resulting in improved integration of the prosthesis into the body image (4).

Discussion: The body of published evidence for the clinical benefits of multiarticulating prosthetic hands is still very limited. Two studies have found significant improvements with the Michelangelo hand. No studies have been found with multiarticulating hands that offer even more grip patterns. Therefore, it remains unclear if the clinical benefits of all multiarticulating hands are comparable or if there is a correlation between the number of available grip patterns of a hand and the magnitude of clinical benefits it may deliver.

References

1. Belter JT, et al., J Rehabil Res Dev 2013;50(5):599-618.

2. Niet Otr OV, et al., Prosthet Orthot Int 2010;34(2):216-220.

3. Pröbsting E, et al., J Prosthet Orthot 2015;27(2):46-52.

4. Luchetti M, et al., J Rehabil Res Dev 2015;52(5):605-618.

Disclosure: Andreas Kannenberg is a full-time employee of Otto Bock.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Handsmart Group: communication and global peer support for those engaged in rehabilitation of individuals with upper limb absence

Authors: Birgit Bischof, Debra Latour, Diane Atkins, Agnes Sturma, Liselotte Hermansson, Julie Klarich, Sandra Ramdial, Eitan Raveh, Shawn Swanson Johnson, Kristi Turner, Claudia Winkler, Daniela Wüstefeld, Paula Wijdenes, Wendy Hill, Ayala Nota and Karen Roberts

Abstract: BACKGROUND & AIM: Clinical teams in upper limb prosthetics are challenged on a daily basis due to constantly changing environment and poor education. With regard to this, the Handsmart Group was formed in February 2016 to support comprehensive clinical practice, and empower peers by creating an open access and international network.

METHOD: Sixteen international clinicians are members of the Handsmart core group and work on a voluntary basis. The larger group divided into four working groups based on their aims: enhance public awareness for the upper limb prosthetics community, establish a network among peers worldwide, support clinical practice with evidence based rehabilitation resources and acquire sources of consistent funding. Each work group discusses and votes on relevant issues to achieve their goals. The larger group will meet in person once a year to evaluate and discuss the results, methods and organization. Peers are invited to join the Handsmart network to support the group vision: Provide the most holistic rehabilitation approach for every person with upper limb loss or upper limb difference, now and in the future.

RESULTS: Based on the vision, mission and the shared core values of the group, fundamental strategic keys (Figure 1) were identified. The group developed fundamental work plans for the first year. A website (http://handsmartgroup.org) was launched in autumn 2016. This online platform supports the group to create and enlarge an international peer network, to share information, access resources and to support clinical practice for international clinicians in upper limb prosthetics.

To better accomplish the Handsmart vision and support clinical practice with evidence-based rehabilitation resources, the group will seek for evidence to support the suggested rehabilitation.

DISCUSSION & CONCLUSION: The Handsmart core members invite external parties involved in upper limb loss/difference rehabilitation to collaborate and support the group. All initiatives will enable successful work in the promotion of its mission and will aim to improve the daily lives of clinical teams in upper limb prosthetics.

The international consortium of expert clinicians would like to thank the companies Ottobock and ProsthetiKa for their financial support and Ottobock for initiating this project. The Handsmart Group is independent and follows the international needs and interests of all people. There is no financial interest in this group. The handsmart group is currently in the process of incorporating as a 501c3, non-profit, in the United States.

DISCLOSURE: This is a work of all 16 Handsmart Group members.

Theme: Clinical Prosthetics

Poster Title: Postural asymmetries in persons with a unilateral transhumeral upper limb amputation: Biomechanical effects of wearing a prosthesis

Authors: Takashi Nakamura and Yusuke Okita

Abstract: BACKGROUND: In persons with a unilateral upper limb amputation, postural asymmetries such as trunk rotation or scoliosis are observed. Although wearing upper limb prosthesis may be considered to mitigate the effects of limb loss on posture, few studies have been conducted regarding the influence of prosthesis during walking.

PURPOSE: The present study investigated the biomechanical influences of prostheses on the walking posture of patients with a unilateral transhumeral upper limb amputation. Kinematic analysis was used to quantify the impact of wearing different types of upper limb prostheses during ambulation, compared with not wearing an upper limb prosthesis.

METHOD: Five male patients with a unilateral transhumeral upper limb amputation (average age: 44.8 ± 16.3, average period since amputation: 2.6 ± 1.6 years) were investigated. The patients walked on a treadmill (ADAL3D-S, Medical Development) for 3 minutes (walking speed: 4.0 km/h). Patient posture was analyzed in the following five situations: 1) without a prosthesis, 2) with a socket (average weight: 200 ± 15 g), 3) with a cosmetic prosthesis (average weight: 634 ± 23 g), 4) with a body-powered prosthesis (average weight: 1220 ± 107 g), and 5) with a myoelectric prosthesis (average weight: 1600 ± 119 g). The kinematic parameters of their postures were biomechanically analyzed using 10 optoelectronic cameras (VICON, Oxford Metrix, UK).

RESULTS: The kinematics revealed that the patient's trunk rotated toward the intact side when the prosthesis was not used, and all patients swung the intact arm; the trunk slightly leaning to the intact side. When patients wore the prosthesis, the rotation and lean of the trunk decreased. The axis of the trunk rotation moved to the center of the patient's body from the intact side. The heavier the prosthesis was, the more symmetric the posture became. When wearing the prosthesis, the improved symmetry enabled increased prosthetic arm swing and decreased the trunk rotation

CONCLUSION: From the biomechanical point of view, this study showed that the patient's body posture was significantly improved when a prosthesis was used. Compensatory movements, such as abnormal swinging of the contralateral arm, were reduced. Arm swing has been suggested as a useful motion in counteracting trunk rotation in gait. The reestablishment of upper limb mass may have improved the patient's overall balance, thus, improving confidence while ambulating.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Linear, kurtosis and Bayesian filtering of EMG drive for abstract myoelectric control

Authors: Matthew Dyson, Jessica Barnes and Kianoush Nazarpour

Abstract: Introduction: Artificial limbs, or prostheses, can help individuals perform essential activities of daily living after limb loss or in the case of people born with congenital deficits. The surface electromyogram (sEMG) is a method whereby the electrical manifestation of neuromuscular activity may be recorded in a non-invasive manner. Signal processing of sEMG is currently the most prevalent method used to control active hand prostheses. For control purposes sEMG is typically transformed into a feature space representation prior to presentation to a controller or classifier. In this study we compare three signal processing techniques for myoelectric control based on low level EMG contractions: mean-absolute-value (MAV), a Bayesian estimate of the EMGs 'neural drive', and sequentially updated real-time Kurtosis.

Method: Tests were performed while ten participants learned to control an abstract myoelectric-controlled interface (MCI). EMG was recorded from the abductor pollicis brevis (APB) and the abductor digiti minimi (ADM). Participants used isometric muscle co-contraction to control the position of a 2-D cursor toward pseudo-randomly presented targets. After each trial participants received a score indicating how well they were able to hold the cursor within the target area.

Results: The Linear filter outperformed the Kurtosis based method and produced similar percent hold rates to the Bayesian method tested. Rates of improvement in overall score were more apparent in the Bayesian and Kurtosis filters, while improvement in target hit rate was largely restricted to the Bayesian filter. Differences in hit rate may have been attributable to the Kurtosis and Linear methods being sufficiently similar for participants to generalise between the two. In contrast, optimal co-contraction behaviour for the Bayesian filter is likely to be different as was the rate at which the cursor moved. Despite significantly less efficient trajectories, the Bayesian filter showed a reduced time required to reach individual targets. Participant performance was analysed with respect to Fitts' Law. Analysis showed decreasing accuracy relative to speed for each filter type. A significant correlation found between participant accuracy and overall cursor speed for the MAV filter, suggesting participants were able to make a speed accuracy trade-off. These results suggest that the slower pace of cursor feedback provided by the MAV filter more readily allows for adaptation in participants control strategy.

Conclusion: Overall results demonstrate both that linear methods can outperform more complex filtering techniques, and that real-time kurtosis may be used as an activation estimator.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Implanted magnets tracking as a novel method for prosthetic hands control

Authors: Sergio Tarantino, Francesco Clemente, Diego Barone, Marco Controzzi and Christian Cipriani

Abstract: Restoring dexterous motor functions equivalent to that of the human hand after amputation requires the implementation of an effortless Human-Machine Interface that bridges the artificial hand to the sources of volition. New research approaches span from invasive interfaces (e.g. peripheral nerve electrodes) to techniques aimed at increasing the number of independent signal sources available for control (e.g. targeted muscle reinnervation). Among those, solutions based on Implantable Myoelectric Sensors (IMES) are very promising. IMES are small electrodes that wirelessly transmit intramuscular EMG signals to the prosthesis. Their main drawback is that they need to be powered wirelessly with unavoidable power consumption. As an alternative solution, within the framework of the MYKI project (ERC-SG #679820), we propose to implant small magnetic markers (MMs) directly in forearm muscles. By doing so, it is possible to detect the muscles deformation during contraction by tracking the MMs using a localizer and use such information to drive a prosthetic limb. We dubbed this the MYoKInetic (MYKI) interface (Fig. 1).

In order to test the feasibility of the MYKI interface, we built a physical mock-up (PMU) of the human forearm aimed at reproducing its muscles' natural position and deformation. Muscles were modelled as a wire attached on one side to a servo motor. Four MMs were attached to four wires in the PMU, associated to four muscles actuating the adduction/flexion of the thumb and flexion of index and middle fingers. The localizer comprised two printed circuit boards, each equipped with three 3-axis magnetic field sensors (HMC5983, Honeywell International Inc.) and a host PC used to solve the magnetic inverse problem (i.e. retrieving the 3D position of the four MMs using the magnetic sensors readout) at 25 Hz. The maximum accuracy and repeatability errors of the system were found to be 16% and 1% the mean stroke of the MMs (13mm), respectively. Albeit large, the accuracy is of minor importance for this system as it relies on the ability to discriminate a movement. The geomagnetic field also affected the system reliability (100% error). However, simulations showed that such disturbances can be attenuated by using a magnetic shield (μr=200000, residual error 0.5%). Future work will focus on increasing the number of MMs tracked and study the influence of magnets orientation.

Implantable MMs are not subject to failure and don't need to be powered, potentially increasing the life time of the implant with respect to previous solutions.

Theme: Clinical Prosthetics

Poster Title: A National Study of Veterans and Service Members with Upper Limb Amputation: Survey development and pilot testing

Authors: Linda Resnik, Sarah Ekerholm and Melissa Clark

Abstract: Background and Purpose: Quality gaps in care to persons with upper limb amputation have been reported. Studies showing dissatisfaction amongst combat Veterans with upper limb loss led to calls for studies to understand needs and improve satisfaction. In 2016, a new longitudinal study was funded to address this gap. The new study includes both telephone surveys and in-person data collection. The purposes of this presentation are to describe the pilot work conducted to test and refine the survey for the new study and report preliminary results.

Design and methodological procedures used: The pilot study had two phases: survey development/cognitive testing to identify problematic items (Phase 1), and pilot testing of the full survey (Phase 2). The full survey was designed to assess demographics, amputation history, prosthesis use, function, quality of life, satisfaction with prosthesis and amputation care, quality of care, and included a risk-benefit assessment of technological advances requiring surgical intervention. The survey included new items, validated standardized measures, and items modified from a prior study. Cognitive testing and pilot testing resulted in refinements to the survey and a decision to administer by telephone only.

Results: Phase 1 included 10 participants; 90% male, mean age 56 years, 30% with transradial (TR), 60% with transhumeral (TH), and 10% with shoulder level amputation (shoulder); 60 % were prosthesis users. Phase 2 included 13 participants; mean age 59 years, 92% male, 38% TR, 46% TH, and 15% shoulder; 77% were prosthesis users. Amongst Phase II prosthesis users, 60% used a body-powered and 40% a myoelectric/hybrid. Seventy percent used two or more types of devices, and 60% used two or more types of terminal devices. Prosthesis users averaged 3.4 hours of use per day, and 40% were dissatisfied with their prostheses. Twenty three percent indicated that they would be willing to consider surgery for osseointegration, 54% for greater prosthesis control, and 31% for sensory restoration.

Conclusions/Implications: The refined survey is ready for use. Preliminary findings suggest that despite availability of multiple types of devices, there was a high prevalence of dissatisfaction with devices. At least half of pilot participants indicated their willingness to incur risk to obtain the benefits of a new or emerging prosthetic technology. Results of the full study will provide nationally representative data and ultimately may be used to improve the quality of care, provision of rehabilitation services and inform FDA regulatory approval.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Myoelectric prosthesis following total thumb amputation

Authors: Vera van Heijningen, Raymon Wijman, Veit Biedermann and Wim Janssen

Abstract: Aim and objectives: In clients with thumb amputation, a passive thumb prosthesis is one possible solution to restore pinch grip and grip to improve hand function. However, the clinical experience of the authors is that this is not routinely a satisfying solution for the client with a total thumb loss.

With the development of Myoelectrically controlled digit prostheses, prosthetic options for partial hand deficits have been widened.

The aim of this study was to investigate the potential benefit of applying a myoelectric controlled thumb in comparison to a passive prosthetic thumb.

This case study presents the process and preliminary results of optimizing the hand function of a client with a total thumb loss.

Case description and methods: A 53-year old woman reported impairment in daily activities as her chief complaint.

The thumb of her right hand was amputated at the level of the carpo-metacarpal joint, following a period of severe suffering from Complex Regional Pain Syndrome type II as a result of a cat bite. Her left arm showed severe signs of overuse as a result of the limited capacity of her right hand. This case report describes the process of designing and manufacturing a myoelectric thumb prosthesis. Including the rehabilitation process that followed

Findings and outcome: This case-report also describes the rehabilitation process which was focused on regaining balanced use and interlimb interaction in daily activities. Experiences, advantages and disadvantages of the three options (no prosthesis, passive prosthesis or myoelectric prosthesis) will be shared and discussed. Patient rated outcome measures show positive results.

In conclusion: The myoelectric thumb prosthesis restored the hand function beyond the client's expectations. The client has regained the ability to be fully active in her daily life, in the most practical, comfortable and secure way as possible. Furthermore, her self-esteem and self-image have grown.

The results obtained in this case report do not automatically transfer to other cases. Further research is needed

Clinical relevance: No case-report or any literature on this topic was found by the authors. This case report has identified a potential improvement of hand function for clients with total thumb amputation by using a myoelectric thumb component.

Theme: Occupational Therapy & Outcome Measures

Poster Title: User training for pattern-recognition based myoelectric prostheses using a serious game

Authors: Morten Bak Kristoffersen, Andreas Franzke, Alessio Murgia, Corry van der Sluis and Raoul Bongers

Abstract: Individuals with upper-limb deficiency who are fitted with a prosthesis are normally trained in the use of such device. This is even true for individuals who are fitted with a myoelectric prosthesis that uses control algorithms based on pattern-recognition, despite the intent of pattern-recognition control of exploiting "intuitive" phantom movements. Conventionally, training individuals for pattern-recognition control usually involves an expert who guides the user to produce electromyogram (EMG) signals that optimize pattern recognition. In the training the individual is stimulated to adapt their EMG signals as to make them more distinct in terms of the resulting patterns. To achieve this, for instance, small movements can be added to the basic pattern, such as flexing the little finger during open hand. Although training improves online accuracy it still involves considerable trial and error. Moreover, expert guidance is currently done based on visual perusal of EMG patterns or features thereof and not based on specific metrics characterizing those EMG signal patterns. Rather than using intuitive phantom movements for control, we instead propose to use those phantom movements which are most distinct in terms of EMG. To find the set of phantom movements that provides the most distinct EMG activation patterns, we propose to use a serious game. Using a game, we can train individuals to make EMG patterns distinct while performing them in a robust manner. This game is controlled using the EMG captured from 8 electrodes positioned around the forearm. Inspired by the work of Radhakrishnan et. al and Pistohl et. al, the EMG from each electrode is mapped to a direction of the game avatar in the 2D environment. We hypothesize that this training will make individuals utilize their EMG activation space to a greater extent and become better at generating only EMG activity at specific electrode sites so that patterns are more distinct.

We are currently conducting an experiment in which 4 experimental groups receive different kinds of training. Group 1 receives conventional training without coaching. Group 2 receives conventional training with feedback. Group 3 receives training with the proposed serious game and group 4 receives training without any feedback (control). The learning effects between groups are analysed using the metrics proposed by Bunderson et al. and the motion test.

References:

1. Radhakrisnan S. et. al, J Neurophysiol. 2008

2. Pistohl T. et. al, Ann Biomed Eng. 2013.

3. Bunderson NE et. al, IEEE T Neur Sys Reh. 2012

Theme: Sensory Feedback

Poster Title: Interrogating the functional interpretation of joint movement illusions using intentional binding

Authors: Courtney Shell and Paul Marasco

Abstract: Sensation of joint movement provided through a vibration-induced illusion has potential use in restoring lost kinesthetic sensations, such as those caused by amputation. In order to be usefully employed, the way in which sensations provided by the illusion are incorporated into the body's internal model for motor control must be explored. While literature suggests that vibration-induced illusion of a joint movement is generated by providing vibration to the antagonist muscle (e.g., elbow flexion illusion induced by vibrating the triceps), perception of limb movement appears to be more complex as vibration of a given muscle in targeted reinnervation amputees generates an illusion of joint movement associated with contraction of the vibrated muscle. To explore how vibration-induced illusion of joint movement is interpreted by the body's internal model, we investigated perceived compression of time (intentional binding) between an auditory signal and completion of a participant-controlled virtual arm movement paired to the movement illusion. In this paradigm, when conditions are more natural subjects experience compression of the time interval between an action and results of the action. Thus, the movement of a virtual arm shown to the subject that most closely matches the internal model's interpretation of the vibration-induced illusion can be identified.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: A novel passive compliant wrist with automatic switchable stiffness

Authors: Federico Montagnani, Marco Controzzi and Christian Cipriani

Abstract: State of art upper limb prostheses lack several degrees of freedom (DoF) and force amputees to compensate for them by changing the motion of their arms and body. Such movements often yield to articulation injuries and in general represent a discomfort; nonetheless these could be prevented by adding DoFs, for instance, to an articulated passive wrist. Available stiff or compliant wrists with passive flexion/extension and/or radial/ulnar deviation are sub-optimal solutions. Indeed, stiff wrists induce the individuals wearing them to perform exaggerated compensatory movements during the reaching phase while compliant wrists proved to be unpractical while manipulating heavy objects. Here we present the concept of a wrist capable of combining the benefits of both stiff and compliant wrists. It is provided with two switchable levels of passive compliance that are automatically selected depending on the grasp phase.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Real-time proportional control of digits

Authors: Agamemnon Krasoulis, Sethu Vijayakumar and Kianoush Nazarpour

Abstract: Current powered hand prostheses offer the potential of individual digit control. In practice, however, sequential control strategies are employed (e.g. grip control) which lead to under-actuation of the prosthesis. Arguably, adoption of proportional control strategies can improve the ease of use and naturalness of upper-limb prostheses. Previous work has demonstrated the feasibility of proportional finger control with invasive methods, that is, by using intra-muscular electrodes. Although it has been shown that it is feasible to reconstruct finger joint angle trajectories offline by using surface electromyography (sEMG), the real-time efficiency of such control systems has not been previously evaluated. In this study, we implemented a real-time, proportional finger joint angle controller for the 5 degree-of-freedom (DOF) IH2 Azzurra anthropomorphic hand, and tested its performance with ten able-bodied and two trans-radial amputee subjects. Myoelectric activity was recorded on the participants' forearm proximal to the elbow, by using 16 sEMG sensors, which were equally spaced around the subjects' forearm. The recorded EMG activity was used to decode the intended degree of individual finger flexion and thumb opposition by using a linear regression system (Wiener filter), thus mapping muscle activity to 5-DOF finger joint angles. Ground truth data were collected by using a data glove placed on the participants' contralateral hand. Two different sets of experiments were performed for both populations of participants. In the first experiment, participants were asked to modulate their muscular activity in order to control the robotic hand such that its posture matched a target posture presented to them on a computer screen. At the end of each trial, participants received a performance score that was based on the L1-distance between the target and performed postures. The analysis of results from this experiment provides helpful insights into the mechanisms underlying the learning of controlling a 5-DOF robotic hand. In the second experiment, participants were asked to control the artificial hand to perform a pick-and-place task, again by modulating their muscular activity. Preliminary results from this part of the study shed light on the usability of proportional finger control for performing activities of daily living (ADL). We value the findings of our study as a valuable step towards the development of truly dexterous, non-invasive hand prostheses.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Proportional and simultaneous estimation of combined finger movements from high-density surface EMG

Authors: Sigrid Dupan, Michele Barsotti, Ivan Vujaklija, Dick Stegeman, Bernhard Graimann, Dario Farina and Strahinja Dosen

Abstract: BACKGROUND: In order to mimic the dexterity of the human hand, modern hand prostheses allow control of individual fingers. However, proportional and simultaneous control of individual fingers using myoelectric signals is still to be achieved. For practical application, it is important to minimize the number of sensors and the amount of calibration data. The aim of the present study was to test the feasibility of estimating finger forces during both single and combined finger movements using a training set of only 6 motions and a reduced set of electrodes.

METHODS: Five subjects performed 19 flexion movements: 5 individuated finger flexions, and 14 combinations of 2 to 5 fingers. The finger forces were measured using the Amadeo robot (Tyromotion GmbH, AT), and the surface electromyography (EMG) was recorded through a 256-channel high-density electrode grid (OTBioelettronica). Ridge regression was applied to simultaneously predict the forces of all fingers. The only movements used in the training were the single finger flexions, and the simultaneous flexion of all fingers. The quality of estimation was evaluated by computing the root mean square error (RMSE) between the estimated and desired force normalized (nRMSE) to the maximum of the desired force. The regression was performed using a full set of electrodes and reduced sets comprising 48 and 24 electrodes. The statistically significant difference was tested using a one-way ANOVA ($p<0.05$).

RESULTS: The average nRMSE for the training data and full electrode set was 0.12±0.03, and there was no significant difference in the quality of estimation between the fingers. However, the performance decreased ($p<0.001$) when using less electrodes (48 electrodes: 0.20±0.04; 24 electrodes: 0.22±0.04). The estimation of the finger forces during combined motions (test data) resulted in nRMSE of 0.40±0.12, and the performance was significantly better ($p=0.003$) for the ring finger (0.33±0.08) compared to the thumb (0.49±0.12). There was no difference in the quality of estimation for the combined motions when reducing the number of electrodes.

CONCLUSION: The study showed that the finger forces can be estimated proportionally and simultaneously using a simple method and a reduced training set. However, the average precision of estimating combined finger movements was not high, and the estimation of the thumb proved to be the most difficult of all the fingers. This likely reflects an increased role of intrinsic muscles in thumb control. Remarkably, reducing the number of electrodes did not significantly decrease the performance for the combined movements.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Evaluation of classifiers performance using the Myo armband

Authors: Irene Mendez, Ásgerdur Arna Pálsdóttir, Dagbjört Helga Eiríksdóttir, Mathias Faulkner, Nicksan Sriranjan, Asim Waris and Ernest Nlandu Kamavuako

Abstract: To provide amputees with intuitive prosthetic control systems, surface electromyography (EMG) has shown promising results in several studies. Myo armband (MYB) is a wireless, ready-to-use technology developed by Thalmic Labs, able to record eight EMG channels with limited frequency bandwidth (<100 Hz). The aim of this study was to evaluate the performance of five classifiers in order to assess the suitability of the MYB to provide reliable accuracy in comparison to the conventional EMG systems (CONV). Eight able-bodied subjects performed nine hand gestures in a crossover acquisition design. Six time-domain features were extracted from the data to evaluate the offline classification error of five classifiers: Linear Discriminant Analysis (LDA), Support Vector Machine (SVM), K-Nearest Neighbors (KNN), Naive Bayes (NB) and Neural Networks (NN). Friedman's test showed no significant difference between CONV and MYB with six channels (P=0.10) with mean classification error of LDA (5.82 ± 3.63% vs. 9.86 ± 8.05%), SVM (9.70 ± 6.02% vs. 11.01 ± 8.79%), KNN (8.30 ± 6.00% vs. 11.12 ± 8.94%), NB (12.48 ± 8.51% vs. 13.77 ± 9.76%) and NN (1.77 ±1.28% vs. 4.64 ± 4.25%) for CONV and MYB, respectively. Although lower classification error was obtained, no significant improvement was found between MYB using eight and six channels (P=0.16).

Theme: Upper Limb Prosthesis Device Design

Poster Title: Understanding errors in pattern recognition-based myoelectric control

Authors: Jason Robertson, Kevin Englehart and Erik Scheme

Abstract: Recent advances in pattern recognition-based myoelectric control have allowed the technology to be commercialized after decades of controlled laboratory and clinical usage. Despite this success, challenges remain; one of the most critical of these is susceptibility to unintended movements. These errors often require correction to accomplish the desired task, a frustrating process that can hinder device adoption. Although many studies have examined systemic causes of error, such as limb position, electrode shift, and changes in patterns over time, no study to date has investigated how errors actually occur in real time. A handful of studies have analyzed the training data to establish what, if any, characteristics are predictive of successful control, but with little success. In this work, we examined and characterized the nature of errors as they occurred during a real-time myoelectric control task.

To better understand how errors occur, 24 subjects (50% female, 92% right-handed, age 25.8±3.2 y) were recruited to participate in a myoelectric control task. Subjects elicited eight sample contractions of four movement classes (wrist pronation, wrist supination, chuck grip, and hand open) and a no-movement class, which were used to train a classifier. This classifier was then used to control a cursor through a virtual targeting task, during which the myoelectric signals and the resultant cursor position were recorded. Indices of separability, repeatability, and variability were calculated from the training data, while outcome measures based on Fitts' Law were computed for the usability trials.

A thematic analysis of the real-time errors resulted in identification of three major types of error. The first, overshoot, described when users moved past or through a target without stopping. The second, bounceback, referred to an unintentional activation while the user attempted to stop. The third category encompassed all other active errors that resulted in movement away from the target. Within these error categories, several descriptive metrics were computed, including proportional control values, classifier confidences, and feature space distance metrics.

Although traditional Fitts' law metrics could not be predicted from the training data alone, several of the proposed real-time error characterization metrics could be. Although these measures were calculated during Fitts' Law tests, their results were not found to be correlated with the more traditional Fitts' Law measures. This work suggests that prediction of future performance of pattern recognition-based myoelectric control may be achieved through a better understanding of the nature of errors.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Controller Selection for Myoelectric Prosthetic Hands

Authors: Eric McClain and Sanford Meek

Abstract: Powered prosthetic hands are traditionally controlled using proportional control, where the motor voltage varies in proportion to the differential EMG signal form antagonistic muscles. This method of control performs adequately in position control as well as grasping durable objects perform poorly where force control is needed, such as grasping brittle objects. We are seeking to improve the ability to control grip force of a hand prosthesis through modifications to the control scheme for both a basic and a responsive prosthetic hand. For the basic hand in this study we used an Ottobock MyoHand with direct motor drive. For the responsive hand internal feedback control was implemented on the MyoHand to compensate for the high effective inertia and friction of the system. The two modifications under consideration are EMG gain scheduling and adaptive time constant low pass EMG filtering. EMG gain scheduling is a simple scheme which consists of changing the EMG signal gain to one of two user selected values based on the activity. One value is for control of an open hand and the other for control while an object is grasped. The adaptive EMG filter varies the time constant of a low pass filter based on the control signal to allow the filtered signal to track fast control signals while filtering out noise when the EMG signal is relatively constant.

Two experiments were performed to compare the variations of myoelectric prosthetic hand controllers. Control of force, control of position and manipulation of a brittle object were evaluated. The manipulation task was performed using a manipulandum that slips at low grasping force and breaks with excessive grasping force. Force and position tracking were evaluated by the ability to track desired values displayed to the subject. Users self-select separate EMG gains for force and position control. Evaluations were performed with both fixed and scheduled gains. The adaptive EMG filter was compared against a fixed time constant low pass filter for each of these conditions. For the basic (Ottobock MyoHand) it was found that the adaptive filter showed no significant improvement but EMG gain scheduling showed a significant increase ($p<0.05$) in performance and user rating of the brittle object manipulation. For the responsive hand (Ottobock MyoHand with internal control) it was found that EMG gain scheduling showed no significant improvement but the adaptive filter showed a significant increase ($p<0.05$) in performance and user rating in force control and brittle object manipulation.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Differences in Intramuscular EMG Activity in Able-bodied Subjects and Transradial Amputees during Structured Hand Movements

Authors: Misagh Mansouri, Carl Beringer, David Weir, Tyler Simpson, Michael Munin, Michael Boninger, Lee Fisher, Jennifer Collinger and Robert Gaunt

Abstract: Introduction: Commercial myoelectric prostheses have limited capabilities to simultaneously control multiple degrees of freedom. These prostheses typically rely on signals recorded from surface EMGs placed on the residual limb, which are not the full set of extrinsic hand muscles required to actuate individual fingers. In addition, standard control approaches usually use pattern recognition or map muscle activity to specific prosthesis movements while largely ignoring underlying biomechanics. Understanding the coordinated activity of extrinsic hand muscles and how their activity results in individual joint movements across a wide range of hand configurations is an essential step towards improving the dexterity of prosthesis control. Here we use dimensionality reduction and clustering techniques to investigate these relationships in able-bodied subjects and an amputee.

Methods: All procedures were approved by the University of Pittsburgh Institutional Review Board and the US Army Human Research Protection Office. Nine able-bodied subjects and one transradial amputee were recruited for this study. We recorded intramuscular EMG (iEMG) from 16 extrinsic hand muscles targeted using ultrasound. Subjects were instructed to attempt 45 movements that included individual finger and wrist movements in different wrist postures (flexed, extended, pronated, supinated and neutral). iEMG signals were recorded at 30 kHz, high-pass filtered at 20 Hz, rectified, and then low-pass filtered at 4 Hz. Principal component analysis (PCA) and hierarchical clustering analyses (HCA) were used to study EMG activity across the different movements and subjects.

Results & Discussion: We found a major difference in the number of principal components (PCs) required to explain 90% of the variance in the EMG data between the amputee (5 PCs) and able-bodied subjects (10- 11 PCs). In addition, HCA clustered the movement trials into four major subgroups consisting of wrist flexion/extension, wrist pronation/supination, wrist adduction/abduction, and all fingers based on all 10 subjects' EMG activity patterns.

The differences in the number of PCs between able-bodied subjects and the amputee could potentially be explained by the reduced muscle set in amputees, challenges related to muscle targeting, or more interestingly, changes in the ability to voluntarily make certain movements as a result of the chronic limb loss. The HCA results can be used to help visualize and understand the underlying patterns of EMG activity. The results of this study can be used to inform the design of bio-inspired controllers that generate prosthesis control signals from the biomechanical function of the muscles and the resulting movement dynamics.

Theme: Sensory Feedback

Poster Title: Development of a simulated sensory motor prosthesis: a device to research prosthetic sensory feedback using able-bodied individuals

Authors: Tarvo Kuus, Michael Dawson, Katherine Schoepp, Jason Carey and Jacqueline Hebert

Abstract: Sensory feedback is a desirable feature for prostheses; however, research studies are limited in scope by the relatively small proportion of persons with upper-limb amputation. This impedes our ability to study the effect that various forms of sensory feedback have on device control and function. A Simulated Sensory Motor Prosthesis (SSMP) was developed to allow able-bodied users to perform functional tasks similar to a transradial amputee using a prosthesis, with the addition of somatotopically matched mechanotactile haptic sensory feedback. The intent is to assess the impact of relevant prosthetic sensory feedback on functional task performance.

This paper reports the design and development of the SSMP, which mimics the function of a prosthetic device, while also providing optional mechanotactile feedback. The device passed through many rapid iterations using 3D modelling and 3D printing, combined with traditional manufacturing techniques. The control of the device is similar to traditional transradial myoelectric prostheses, and required the development of training and testing protocols for new users. Data from twelve participants was collected and preliminary results are presented. A standard training protocol was successful at improving skill level to allow performance of 4 functional tasks. Participants gave higher ratings for confidence in grip security with the sensory feedback, compared to without. Two of the four tasks showed lower error rates using the sensory feedback. The SSMP provides flexibility to test and iterate different feedback modalities and control strategies as a first-pass with able-bodied participants. This offers the potential to save significant clinical and amputee participant time.

Theme: Clinical Prosthetics

Poster Title: Factors influencing long term prosthesis use

Authors: Dan Conyers, John Miguelez and Nathan Kearns

Abstract: BACKGROUND: Experienced Upper Limb(UL) prosthetists regularly engage patients with a successful long term prosthesis wear and use history. Clinical concentration to quantify the primary contributing factors to this outcome is paramount to consistent clinical practice. Patient population specific factors such as amputation level, patients' prosthesis expectations, experience and preferred type and demographic characteristics must be considered when making clinical decisions. While, there are many opinions as to what qualifies as prosthetic rehabilitation "success" (e.g., active grasp, user satisfaction). Clinical observation demonstrates a variance in prosthesis wear time among some patients and may serve as a common marker among UL patients. As such, the primary aim of the current study is to better understand which, if any, condition-related or demographic variables influence long term UL prosthetic rehabilitation "success."

METHODS: Representative case studies demonstrating the scope and variety of factors impacting long term prosthesis wear and use were completed. These representatives' results were compared to prosthetic rehabilitation patient survey results to identify corresponding factors influencing outcomes. One hundred and eighteen patients the Comprehensive Arm Prosthesis and Rehabilitation Outcome Questionnaire-Revised© (CAPOQ-R©) as a standard of clinical care. A series of t-tests, univariate analyses of variance, and simple linear regression analyses were conducted to assess associations between a) key demographic and condition-related variables and b) prosthetic wear time were completed.

RESULTS: Comparison of representative case studies and survey results confirmed prosthetist expectations of prosthesis wear history and daily wear time. Analyses of survey results found no significant difference in prosthetic wear time based on biological sex, education level, age, current job status, area of the country, trauma type, or primary prosthesis type. However, results showed a significant difference based on the amount of time patients had their prosthesis [$t(105) = 2.46$, $p=.016$]. More specifically, patients who had their prosthesis for more than five years ($M=9.59$, $SD=4.93$) wore their prosthesis for significantly more hours on a daily basis than participants who had their prosthesis for less than five years ($M=7.21$, $SD=4.15$).

CONCLUSION: Results of the clinical observation and patient responses suggest UL amputees with long term experience utilizing a prosthesis wear their prosthesis for longer periods of time each day. Results do not support any general or patient population specific demographics as having a significant impact on prosthesis wear time. Further research is warranted to evaluate the impact of other factors with the potential to influence long term wear and use of an UL prosthesis.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Prosthesis Incorporation: an outcome metric to assess tool incorporation of a prosthetic limb

Authors: Adam Wilson, Satinder Gill, Dan Blustein and Jon Sensinger

Abstract: As new types of feedback systems are realized for prosthetic limbs, it is important to be able to assess the impact of those feedback systems on the amputee's experience. The Prosthesis Incorporation (PIC) outcome measure evaluates an amputee's level of tool incorporation of a prosthesis with feedback. The PIC scoring is performed using a modified crossmodal congruency test (Gill et al. 2016), while parameters such as training time, feedback agency (trust of feedback), spatial congruency (feedback distance from expected location), and physiological correspondence (naturalness of feedback) are controlled or measured.

The PIC outcome measure can be administered in approximately 20 minutes and immediately provides a quantitative measure of tool incorporation. The test uses feedback pairs to measure the user's reaction time while the pairs of feedback (feedback from the prosthesis feedback system plus visual feedback) are presented in complementary fashion (congruent) vs conflicting fashion (incongruent). The score is calculated as the mean reaction time difference between congruent and incongruent stimuli over four sets of 64 trials. A further assessment can be administered by delaying the user's feedback while measuring the delay in their actions (Cipriani et al. 2014). This additional testing provides a measure of the user's feedback agency.

Our results, on 60 able-bodied subjects and 6 subjects with an upper limb amputation, show a proportional relationship between training time and PIC score, a proportional relationship between feedback agency and PIC score, a proportional relationship between physiological correspondence and PIC score, and an inversely proportional relationship between PIC score and spatial congruency. Based on this information and the results of the administered tests, engineers and clinicians can adjust and tune the amputee's feedback system to provide a stronger sense of incorporation of their prosthetic limb if necessary.

References

S. Gill, A. Wilson, D. Blustein, J. Sensinger, "A modified cross-modal congruency task reduces sensitivity to overexposure," submitted for publication.

C. Cipriani, J. L. Segil, F. Clemente, R. F. ff Weir, B. Edin, "Humans can integrate feedback of discrete events in their sensorimotor control of a robotic hand," Experimental Brain Research, vol. 232, no. 11, pp. 3421–3429, Nov. 2014

Theme: Occupational Therapy & Outcome Measures

Poster Title: PHAM: Prosthetic Hand Assessment Measure

Authors: Christopher Hunt, Rahul Yerrabelli, Caitlin Clancy, Luke Osborn, Rahul Kaliki and Nitish Thakor

Abstract: Current methods of assessing the functionality of prosthesis systems are often qualitative in nature. As such, there are issues with evaluation consistency and difficulty scaling these assessments across patient populations. Here, we describe an alternative outcome measure, the Prosthetic Hand Assessment Measure (PHAM) which quantifies the performance of manipulation tasks using body kinematics. Task performance scores are composites of individual deviation metrics and allow for standardized comparison across patient populations. It is our hope that the PHAM may aid both engineers in prosthetic systems development and clinicians in patient functionality assessment.

Poster Session C

Day 3: Thursday, August 17, 2:45PM-3:45PM

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Upper/Lower Limb Myoelectric Control	Factor Analysis of Upper Extremity Prosthetic Patient Acceptance	8	Gerald Stark
Occupational Therapy & Outcome Measures	An update: prosthetic user-satisfaction and client-centered feedback form	18	Debra Latour
Clinical Prosthetics	Case Study. Fitting a Unique Pediatric Congenital Bilateral Elbow Disarticulation	20	Alistair Gibson
Upper/Lower Limb Myoelectric Control	Powered Flexion Wrist With Electric Terminal Device - Development and Preliminary Clinical Trials	23	Jeff Christenson
Upper Limb Prosthesis Device Design	Patient-specific optimum motions: a need for mind shift in myoelectric control of prostheses?	26	Asim Waris
	Pre-clinical application of muscle synergies for abstract myoelectric control	34	Kianoush Nazarpour
Occupational Therapy & Outcome Measures	Control of isometric grip force, visual information processes, and Fitts' law	54	Zachary Thumser
Clinical Prosthetics	Design and evaluation of a novel sensory-motor transhumeral prosthetic socket: a case study	60	Jonathon Schofield
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Poster Session C – Abstracts

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: Factor Analysis of Upper Extremity Prosthetic Patient Acceptance

Authors: Gerald Stark

Abstract: Very few studies have provided statistical support to assess the overall clinical probability of wear. In a recent survey of upper limb prosthetic practitioners collective estimations were made with respect to the priority of the various factors that contributed to Upper Limb rejection as well as the rejection rates by level. From these factors a Bayesian forecasting model was constructed to provide an initial estimation of prosthetic acceptance

From initial phone interviews 12 factors were identified as possible contributors to overall acceptance including: Amputation Level, Functional Advantage, Patient Gadget Tolerance, Time to Initial Fit, Confidence of Prosthetist, Quality of Patient/Prosthetist Relationship, Socket and Harness Comfort, Weight, Cosmetic Quality, Therapy and Training, Peer and Family Support, and Age of Patient. A survey was constructed and posted on a third-party survey hosting website from October 20 to November 8, 2013. There were 58 respondents who self-assessed their skill level which was normally distributed among novices, intermediates, experts, and specialists

Aggregate responses with respect to level were recorded to be 79.6% for transrandial, 57.8% for transhumeral, and 32.8% for shoulder disarticulation which is fairly similar to the original study done in 1958 which indicated 75% for transhumeral, 61% for transhumeral, and 35% for shoulder disarticulation (Berger, 1958). The aggregate opinion was that "Amputation Level" was the highest at 79.6, followed by "Functional Advantage" at 78.3, "Socket and Harness Comfort" at 77.7, "Peer and family Support" at 76.3, "Amount of Therapy and Training" at 73.5 and "Quality of Patient-Prosthetist Relationship" at 72.6.

From this survey of the 12 factors those with the most consistent significance are listed in order: 1) Amputation Level, 2) Functional Advantage, 3) Socket & Harness Comfort, and 4) Peer/Family Support and 5) Prosthetic Competency. Many examinations fail to also include the important role of the peer and family support as well as the prosthetist-patient relationship. There are methods of functional prediction in lower extremity prosthetics such as the AMPPRO Ambulation Test and Amputee Mobility Detector (AMP) (Gailey, 2001, Stevens, 2009) that utilize greater degrees of probability and forecasting. One factor is that clinicians and researchers have attempted to find a single factor that can influence success or failure. This could be that different combinations of factors greatly vary from patient to patient, that prosthetists differ widely in their opinions about rejection, or that prosthetists in general do not have a grasp of why rejection occurs.

Theme: Occupational Therapy & Outcome Measures

Poster Title: An update: prosthetic user-satisfaction and client-centered feedback form

Authors: Debra Latour, Erik Tompkins and Carlene Aniello

Abstract: As healthcare professionals and providers, it is incumbent upon us to provide client-centered care. The consumer demands it, the healthcare industry requires it and our professional ethics mandates it. Patient satisfaction has long been a buzzword and in the prosthetic industry, it includes satisfaction with service delivery as well as with technology. Existing surveys and feedback forms often appear inadequate; and the information is often provided late in the process, hampering functional outcomes and at times does not allow the clinician with the opportunity to rectify dissatisfaction. At Handspring, we have partnered with our adult and pediatric clients to create a feedback loop which speaks to all phases of the prescriptive prosthetic process. We initiate use of the feedback document during the pre-prosthetic phase and extend it through follow-up after delivery of the definitive technology. Items on the form are relevant to comfort, aesthetics, ease of donning/doffing, tolerance to weight, length, socket and harness as appropriate; control systems, reliability, pain and functionality of the technologies. The user grades each item using a 3-point color-coded system that is easy to use by children and adults. It has been translated to Spanish for more seamless use with other measures.

This information is further substantiated with other standardized outcomes measures, particularly those that relate to quality of life and self-perceptions of ability vs disability.

Theme: Clinical Prosthetics

Poster Title: Case Study. Fitting a Unique Pediatric Congenital Bilateral Elbow Disarticulation

Authors: Alistair Gibson

Abstract: Introduction: As clinicians we are presented with challenging and unusual cases on a regular basis.

Sometimes we draw from our experience in fitting similar cases, sometimes the case is so unique and individual that we have never experienced anything like it before, and our support network of experienced specialists have never seen before either.

I was introduced to a 5 year old overseas patient presenting with congenital bilateral elbow disarticulation, with a single long digit growth at around the level of 70% humeral length.

Surgery to provide ROM of this digit had been performed allowing a few degrees on the right side, and around 30 degrees on the left. He had been receiving excellent Occupational Therapy to increase ROM and function. I worked with his therapist to formulate a working prescription.

This presentation will outline the thought process, methodology, casting, fitting, manufacture, delivery, and follow up post delivery.

Success with prosthetic treatment at a young age is dependent on many factors, however sometimes options are limited, and will address the options of follow up care as he returns to his country.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: Powered Flexion Wrist with Electric Terminal Device - Development and Preliminary Clinical Trials

Authors: Ed Iversen, Jeff Christenson, Harold Sears, Gregory Jacobs, Scott Hosie and Tony Jacobs

Abstract: Recent developments in areas as diverse as TMR surgery, pattern recognition, and implantable technologies for muscle and nerve interfaces, have helped to facilitate the feasibility of practical multi-input myoelectric upper limb (UL) prostheses.

Approaching the goal of a multi-degree of freedom (DOF) prostheses, the challenge remains of dependable wrist components for wrist flexion. Components are widely used for wrist rotation – but easily utilized powered flexion is not available.

In a recent study, the kinematics of wrist rotation versus flexion was evaluated through a mathematical model (Iversen, Christenson, 2016). The kinematic analysis shows that a powered wrist flexion/extension device expands the functional workspace.

As part of a U.S. Department of Defense (CDMRP, PRORP program) effort a robust motor-driven wrist flexion component has been developed, beginning with following general targets. The summarized results are in italics:

- Compatible with myoelectric TDs – the project necessarily included new quick disconnect approaches, with the attempt to evolve a new industry standard for a rugged, high strength, and shorter q/d.
- Highly rugged –field trials show the device withstands heavy duty usage, and is water and dirt resistant.
- High torque and speed - at least 2.8 Nm torque has been attained, and may be increased.
- Light weight – a goal of 45 gm has been attained.
- High range of motion (ROM)- 80 deg. of flexion, and 45 deg. extension for both motorized and passive ROM.
- Small scale field trials – three highly active wearers (as of 2/2017) have worn the prototypes as long as four months, in daily use, helping to build the wearer data base.

The Powered Flexion Wrist developments show a positive response to the functionality of the device, specifically:

- Field trial wearers are enthusiastic about the function of the powered flexion DOF for reaching the extremes of their prosthesis ROM with the wrist and TD in a natural position, without awkward positioning of their proximal joints.
- Wearers previously using wrist rotation found that powered flexion adds greatly to function, but does not fully replace the function of wrist rotation.
- The control of multiple DOF of wrist, in a natural manner is a challenge, but existing myoelectric control may be adequate for many wearers, so that additional surgical methods will not be obligatory.
- Exchanging between more than one (or several) terminal devices also will require new hardware developments, for shorter, high strength quick disconnection.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Patient-specific optimum motions: a need for mind shift in myoelectric control of prostheses?

Authors: Ernest Kamavuako, Asim Waris, Irene Mendez and Kevin Englehart

Abstract: Despite the tremendous attempts in the optimization of feature sets and classifiers, the clinical usability of pattern recognition based myoelectric control has considerable room for improvement. In this study, we propose the degree of motion preference (DMP) as a step toward a patient specific optimization of motions.

Six transradial amputees (all males, mean age 31.2 yrs.) took part in this experiment, and participated on seven consecutive days. Five to six surface bipolar electrodes were placed equidistantly about the forearm of the residual limb. Classification of the 11 motions (hand open (HO), hand close (HC), wrist flexion (WF), wrist extension (WE), pronation (PR), supination (SU), side grip (SG) fine grip (FG), agree (AG), pointer (PO); and resting state (NM)) were performed based on seven features using a linear discriminant analysis classifier. Confusion matrices for each amputee were computed. Furthermore, we investigated the best combination of six active motions plus NM per day. The optimum set was selected as the set with the highest average accuracy. Because each day may result in a different optimum set, the DMP across days was quantified as the average accuracy of each motion weighted by its occurrence frequency in the seven optimum sets.

Average classification error was 21.5 ± 4.3 % for all 11 motions but 25.2 ± 4.8 % for the worst combination of 6 active motions (plus rest, thus 7 motions). However, ensemble average error dropped to 5.5 ± 2.5 % using the daily optimum set of motions. Performance of each specific motions seems to vary across days and subjects. Results showed that DMP depends on the patient and that some motions are not preferred.

We have shown that selecting an optimum set of motions may improve performance; and that class performance may vary with time allowing quantification of the degree of motion preference (DMP) that is patient specific. This is clinically relevant towards patient's specific adaptive systems.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Pre-clinical application of muscle synergies for abstract myoelectric control

Authors: Matthew Dyson and Kianoush Nazarpour

Abstract: Introduction: Prosthetics are often controlled by the surface electromyogram (sEMG) of muscles remaining in the limb to which the prosthesis is attached. A major challenge for next-generation prosthetics is to design a proportional control scheme that allows for control of a number of degrees of freedom. Muscle synergies are coordinative structures which act as discrete low-level units typically combined to construct a diverse range of physical movements. In this work we compare use of two channel sEMG against multiple weighted electrodes, representing muscle synergies, in control of an abstract myoelectric user interface (MCI) capable of proportional control.

Method: sEMG was recorded from the forearm in transradial amputee participants and the upper arm in a participant with a transhumeral congenital deficiency. Participants used isometric muscle contractions to operate a MCI which displayed a cursor on the screen. Participants began using a four target interface and progressed to eight targets where appropriate. A 1.5 (s) trial was composed of two 750 (ms) periods, the first for movement and the second for holding the cursor in the target. Percent hold score was calculated based on the duration for which the cursor was within, or in contact with, the target during the hold period. Users were assessed in their ability to use the MCI under two conditions; using a minimal pair of electrodes and using a weighted combination of eight electrodes, as determined by Principal Components Analysis (PCA).

Results: Overall final trial scores achieved using PCA weighted electrodes were significantly higher than those based on two channel sEMG when using the four target interface. Similarly, cursor path efficiency when using the four target interface was significantly higher for PCA based control than use of sEMG. Final scores for the eight target interface were greater using PCA weighted electrodes however additional data is required before significance testing.

Conclusion: Initial results demonstrate that amputee participants can learn to use arm and forearm muscle pairs to flexibly control the position of a myoelectric cursor in a 2-D task environment. Data-driven spatial weighting of sensors generally produced more reliable results than a single pair of electrodes. Improved scores maintaining the cursor within target sectors are mirrored in improved cursor path efficiency.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Control of isometric grip force, visual information processes, and Fitts' law

Authors: Zachary Thumser, Andrew Slifkin, Dylan Beckler and Paul Marasco

Abstract: Fitts' law models the relationship between the amplitude, precision, and speed of rapid movements. It has been widely used to quantify performance in pointing tasks, particularly for Human-computer interaction, but the same model can be applied to analogous tasks. If Fitts' law also applies to grip forces, model parameters would provide a meaningful approach to quantify grasp performance for rehabilitative medicine and prosthetics. We examined the applicability of Fitts' law to a grip force production task, with and without visual feedback (via a force meter), and with target forces presented both explicitly (arrows on the force meter) and implicitly (images of objects). When visual force feedback is available, speed and accuracy of grip force follows Fitts' law (average $r2 = 0.82$). Without vision (operating exclusively on tactile feedback), accuracy of grip force remains high, but force precision is lower, resulting in overall performance that is relatively insensitive to the target presented. Replacing explicit-but-abstract force targets with images of familiar objects that serve as implicit, well-understood targets enabled participants to generate consistent grip forces more reliably. Population means show that the underlying behavior is well-described by Fitts' law with either vision ($r2 = 0.96$) or implicit targets ($r2 = 0.89$), but not for explicit targets without vision ($r2 = 0.54$). Implicit targets allow for a straightforward and realistic see-object-squeeze-object test that uses Fitts' law to quantify the relative speed-precision relationship of any given grasper.

Theme: Clinical Prosthetics

Poster Title: Design and evaluation of a novel sensory-motor transhumeral prosthetic socket: a case study

Authors: Jonathon Schofield, Michael Stobbe, Jason Carey, Paul Marasco and Jacqueline Hebert

Abstract: This work describes a novel myoelectric transhumeral prosthetic socket designed to integrate a custom vibration tactor with improved fit, suspension, and secure electrode contact. A quantitative analysis was performed to evaluate the impact of the novel socket on the interface pressures between the socket and residual limb (RL).

A fundamental challenge in the implementation of advanced upper limb prostheses is the lack of sensory input. In response, haptic systems have been developed; however, practical barriers still exist in translating these systems beyond the benchtop into functional wearable prostheses. Most non-invasive systems employ mechanical devices (tactors) that stimulate strategic locations on the user's RL. A primary challenge lays in the development of prosthetic sockets allowing tactors access to the RL, while maintaining or improving socket fit. A well-fit prosthetic socket will secure the prosthesis to the limb ensuring suspension and security. Yet even well-fit traditional sockets are prone to slip during normal use. In myoelectric systems, this can create a loss of electrode placement resulting in poor or inconsistent control of the components.

Our approach integrated a previously developed tactor into a transhumeral socket, such that a predetermined distal anterior region of the participant's RL could be stimulated. A ¾" diameter window was created allowing the tactor access to the limb. The corresponding region on the participant's prosthetic liner was thinned. A flat build-up was added between the socket and prosthetic elbow providing a mounting surface. Custom brackets allowed attachment of Velcro strapping, providing adjustable affixment of the tactor. To ensure socket fit and electrode contact, a BOA Lace (Denver, USA) and an electrically conductive panel system were implemented. This system provided adjustable compression of strategic areas within the socket, with the panels also serving to make contact with the electrodes in the prosthetic liner. Therefore, tensioning the BOA system ensured firm electrode contact and distribution of pressure, while providing flexibility in the event of socket slip.

To evaluate the impact on socket fit, RL-socket contact pressures were captured using a Tekscan VersaTek system (Boston, USA). Relative pressure magnitudes and corresponding anatomical locations were compared across the novel socket and the participant's well-fit body powered prosthetic socket. Results highlighted reduced maximum pressure magnitudes spread more evenly across the RL while wearing the novel socket.

This work presents a unique solution to practical integration challenges associated with the development of functional sensate prostheses, with further applicability to myoelectric socket design in general.

Theme: Sensory Feedback

Poster Title: Joint-Based Velocity Feedback Improves Myoelectric Prosthesis Performance

Authors: Eric Earley, Kyle Kaveny, Reva Johnson, Levi Hargrove and Jon Sensinger

Abstract: BACKGROUND: Those with upper-limb amputations have reduced sensory feedback, and this likely contributes to difficulties in performing daily activities [1]. Many attempts have been made to improve performance by providing sensory substitution, but few have succeeded with visual feedback present [2]. Research in computational motor control proposes three criteria for augmented feedback to be most useful. First, the feedback should provide information not available to other senses, notably vision [3]. Second, the feedback should have low uncertainty compared to the control of the task [4]. Third, feedback should provide information in the most uncertain reference frame (which, for EMG control, tends to be a local reference frame) [5]. These criteria suggest that a local, joint-based velocity feedback paradigm will improve prosthetic arm control, even for those with unaffected vision.

The aim of this study was to determine if local joint-based velocity feedback improves performance, even with vision present, during control of a 2 degree of freedom (DOF) myoelectric interface.

METHOD: Ten able-bodied subjects participated in the study, which was approved by our local ethics board. After providing informed consent, subjects controlled a myoelectric interface consisting of a virtual shoulder and elbow and were asked to perform time-constrained center-out reaches, arriving at the target within 1.5 seconds. Subjects completed one session with no audio feedback, and one session with audio feedback provided, where amplitude corresponded to joint speed, with a different frequency for each joint. After subjects were familiarized with the task, the simulated dynamics were perturbed by reducing the damping coefficient of the joints. We measured the increase in reaching error and average movement speed post-perturbation, and during reaches to different targets testing generalizability, and modeled the adaptation to these new system dynamics as an exponential decay function.

RESULTS: Subjects experienced a smaller increase in both reach errors and average speed immediately following the dynamic perturbation with audio feedback present. Though reaching errors were within baseline levels during the first generalization trial, speed increased by a smaller margin with audio feedback present.

DISCUSSION:These results suggest that local joint-based velocity feedback helped users recognize changed system dynamics and allow them to adapt faster to these new dynamics, even with vision feedback present.

ACKNOWLEDGEMENTS: Research supported by NSF-NRI 1317379. E. J. Earley was supported by NIH grant T32 HD07418.

Theme: Clinical Prosthetics

Poster Title: Kinematic comparison of body-powered and myoelectric prostheses in users with transradial amputations

Authors: Graci Finco, William Amonette, Thomas Krouskop and Kellie Keener

Abstract: Objective: The purpose of this study was to quantify differences in shoulder, elbow, and wrist range of motion between myoelectric and body powered prosthesis users during three simulated ADLs. Second, we compared the ROM of the involved limb with the sound limb. It was hypothesized that amputees utilizing a myoelectric prosthesis would exhibit less ROM for a given task compared to that of body powered users, and that the prosthetic limb would require greater ROM in all joints than the sound limb to accomplish a task.

Methods: Three subjects participated in this project. One subject used a myoelectric prosthesis, one used a body-powered prosthesis, and one subject used both. Volunteers performed three simulated ADL's with their sound and prosthetic limb: object transfer, drinking from a cup, and hair combing. Three dimensional kinematic data were collected using an eight camera passive optical motion capture system (Vicon, Denver, CO). A 23-marker model was used for data collection. During processing, the markers were manually labeled and gaps were filled using a Woltring algorithm. Upper-limb joint kinematics were modeled to quantify shoulder, elbow, and wrist ROM on the amputated and sound limb during the three selected tasks. Each task was repeated three times, and the middle trial of each task was used to minimize learning effect.

Results: Using the prosthesis did not necessarily require greater ROM in all joints than the sound side in all subjects. All subjects exhibited different movement strategies; body-powered subject 1 typically used the least ROM and body-powered subject 2 used the greatest ROM to accomplish tasks despite identical componentry. The subject that used both a myoelectric and body-powered prosthesis tended to use greater ROM with the myoelectric prosthesis to accomplish tasks.

Conclusion: This case series analysis does not support the commonly held clinical opinion that users of body-powered prostheses use more ROM than users of myoelectric prostheses to accomplish ADLs. Additionally, the prosthetic side did not use substantially more ROM than the sound side to complete the three tasks. This small sample provided unexpected results and highlighted the importance of socket comfort, formal prosthetic training, and choice of components as critical factors prosthetists can control that affect ROM in users of transradial prostheses. Furthermore, the results from this study emphasize the importance of using motion capture to investigate ROM in upper-limb prosthesis users in addition to outcome measures for a more accurate analysis.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Spatial filtering for robustness of myoelectric control on electrode shift

Authors: Jiayuan He, Xinjun Sheng, Xiangyang Zhu and Ning Jiang

Abstract: Electrode shift is one of the factors that degrade the myoelectric control performance. In this study, two spatial filters, Laplacian filter (LF) and circular average filter (CAF), were separately applied on four channels of surface EMG signals, and their respective effects on the classification performance with and without electrode shift were investigated. The results on a classification task of eleven hand and wrist movements showed that CAF could significantly decreased the error rates with electrode shift, while LF significantly increased the error rates. The outcome of this study would benefit the design of the electrodes and increased the robustness of the PR-based myoelectric control.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Introducing a novel training and assessment protocol for pattern matching in myocontrol: case-study of a trans-radial amputee

Authors: Markus Nowak, Raoul M. Bongers, Corry K. van der Sluis and Claudio Castellini

Abstract: Multi-DoF prostheses and advanced myocontrol challenge both engineers and rehabilitation professionals to teach the patient to optimally control the prosthesis, and to assess their addition to functional recovery. This work proposes and evaluates a standardized clinical procedure of a training and assessment protocol characterized by reciprocal adaptation of subject and prosthesis in a case-study.

Theme: Upper Limb Prosthesis Device Design

Poster Title: Improving Optical Myography via Convolutional Neural Networks

Authors: Christian Nissler, Imran Badshah, Claudio Castellini, Wadim Kehl and Nassir Navab

Abstract: In order to improve the accuracy and reliability of myocontrol (control of prosthetic devices using signals gathered from the human body), novel kinds of sensors able to detect muscular activity are being explored. In particular, Optical Myography (OMG) consists of optically tracking and decoding the deformations happening at the surface of the body whenever muscles are activated. OMG potentially requires no devices to be worn, but since it is an advanced problem of computer vision, it incurs a number of other drawbacks, e.g., changing illumination, identification of markers, frame tear and drop. In this work we propose an improvement to OMG as it has been recently introduced, namely we relax he need of precise positioning and orientation of the markers on the body surface. The small size of the markers and their curvature while adhering to the surface of the forearm can lead to missed detections and misdetections in their orientation; here we rather detect the deformations by applying a Convolutional Neural Network to the region of interest around the feature source segmented, from the forearm. The classification-based approach yields results similar to those obtained by other classification based modalities, reaching accuracies in the range of 96.21% to 99.30% when performed on 10 intact subjects.

Theme: Sensory Feedback

Poster Title: Design and Integration of an Inexpensive Wearable Tactor System

Authors: Katherine Schoepp, Michael Dawson, Jason Carey and Jacqueline Hebert

Abstract: Commercial myoelectric prostheses do not provide sensory feedback to the user; developing an inexpensive feedback system that can be easily retrofit onto existing prosthetic components may reduce barriers to clinical translation and testing. We describe the development of an inexpensive and wearable tactor-integrated prosthesis, including the (i) evaluation of sensors that can be retrofit onto existing commercial terminal devices, (ii) design and evaluation of custom mechanotactile tactors, and (iii) design of a custom electronics controller which translates sensor input to tactor output.

Three commercial sensors were evaluated for their ability to instrument individual digits, minimize cost, maximize accuracy, and avoid significant alterations to the prosthetic hand. Evaluated technologies include an FSR (Interlink, FSR 400), a subminiature load cell (Honeywell, FSG020WNPB), and a capacitance sensor (SingleTact, S8-10N). A full-factorial design of experiments was conducted to evaluate sensor responses under different loading conditions including material stiffness, loading rate, sensor contact, and indenter curvature. For low-accuracy applications, the FSR is recommended; for high-accuracy applications, the load cell is recommended where modifications to the prosthetic fingertips are possible, otherwise the SingleTact sensor is recommended.

Two mechanotactile haptic displays were designed; a linear and a cable-driven tactor. Both models use the same servo motor (HiTec, HS-35HD), with a rack and pinion gear system to convert rotational motion to linear, where contact to the residual limb is made via an 8 mm diameter domed head. The cable-driven tactor offers a reduced vertical profile at the tactor head site, however it has a larger overall footprint and draws more current. Tactors can be controlled to set a specific displacement or force, with time delays and output accuracies quantified for each system.

A custom electronic controller was designed to map forces from the sensors on the prosthetic fingertips to the haptic display. The system integrates with the existing prosthetic components and can control up to eight individually mapped tactors, where settings can be adjusted wirelessly. It contains four custom boards in addition to a commercial wireless transmitter (SparkFun, WRL-12580); all boards are contained within a custom electronics enclosure which fits into the forearm of the prosthesis.

The sensors, tactors, and electronics were integrated into a commercial prosthetic arm with minimal increases to cost (material cost \$300 plus \$125 per tactor, excluding assembly time) and weight (100 g plus < 50 g per tactor). Evaluation with an amputee participant will be discussed along with limitations and suggestions for improvements.

Theme: Upper/Lower Limb Myoelectric Control

Poster Title: Design of a Powered Three Degree-of-Freedom Prosthetic Wrist

Authors: Neil Bajaj and Aaron Dollar

Abstract: Development of upper limb prosthetic devices generally focuses on improving the dexterity or functionality of the terminal device. As a result, currently available wrist prostheses tend to be simplistic devices which cannot replicate the function of the unaffected human wrist. Recent studies have shown that the unaffected wrist contributes to manipulation capability as much as the hand. This implies that a prosthetic wrist which is capable of three degree-of-freedom (DOF) motion may be as beneficial to amputees as complex terminal devices.

In terms of mechanical design of wrist prostheses, the vast majority of devices currently available tend to be passive multi DOF or powered single DOF units. Moreover, the multi DOF units tend to be exceedingly long devices, which may be unsuitable for transradial amputees. Many design innovations borrowed from traditional robotic design and implemented in prosthetic hands could serve to improve the mobility of wrist prostheses or aid in creating compact devices. Achieving full 3 DOF wrist motion in a compact volume is an imperative in wrist design. Thus, herein we present the design of a prosthetic wrist which satisfies this design imperative.

Our design consists of a two DOF mechanism responsible for flexion/extension and radial/ulnar deviation in series with a single DOF pronation unit. Majority of our efforts focus on the development of the two DOF parallel mechanism. We chose a U, 2-PSU architecture for the 2 DOF mechanism and optimized the geometric design parameters of the parallel mechanism in order to maximize a novel metric. Whereas typical parallel mechanism optimization would maximize a dexterity or range of motion based metric, our metric encompasses these as well as resultant size of the mechanism, which is particularly relevant for upper limb prostheses. This results in a compact design with reasonable motion capabilities over the workspace.

Theme: Sensory Feedback

Poster Title: Prosthesis grip force modulation using neuromorphic tactile sensing

Authors: Luke Osborn, Harrison Nguyen, Rahul Kaliki and Nitish Thakor

Abstract: For many prosthesis users, the lack of tactile feedback in their limbs can make grasping difficult, especially when handling delicate objects. The lack of tactile feedback is not a new problem for prosthesis users, but how tactile information is handled can have a significant impact on the performance of the system. As prosthetic limbs become more advanced, there is an interest in developing systems that are biologically inspired to more closely mimic how the healthy human system operates. In this work, we utilize a leaky integrate and fire neuron model with spike rate adaption for representing tactile information in a prosthetic hand. We investigate the use of the simulated neuron spike rate in an EMG gain modulating function to limit the amount of grip force applied by a prosthetic hand during grasping of a delicate object. We compare this method with the use of the grip force as an input to the EMG gain modulating function as well as to grasping with no tactile feedback. Results show a reduction in the percentage of broken objects during grasping from 27.5% with no feedback to ~14% when using either grip force or neuromorphic spiking feedback. This demonstrates the feasibility of using a biologically relevant representation of tactile information for improving prosthesis functionality in real-time.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Comparison of functionality and compensation with and without powered partial hand multi-articulating prostheses

Authors: Andrea Wanamaker, Lynsay Whelan, Jeremy Farley and Ajit Chaudhari

Abstract: This study aimed to evaluate differences between Southampton Hand Assessment Procedure (SHAP) outcome measure scores and kinematic movements during functional tasks for individuals with partial hand limb loss with and without a myoelectric prosthesis. The results presented here indicate that an externally powered hand prosthesis restores function to individuals with partial-hand limb loss, as demonstrated by improved SHAP scores and changes in upper limb kinematics. The kinematic analysis of three functional tasks resulted in the prosthesis condition having decreased upper limb joint range of motion (ROM) compared to the non-prosthesis condition.

Theme: Psychosocial/Pain

Poster Title: Modulation of phantom limb pain using epidural stimulation of the cervical dorsal spinal cord

Authors: Ameya Nanivadekar, Santosh Chandrasekaran, Ahmed Kashkoush, Eric Helm, Jennifer Collinger, Robert Gaunt and Lee Fisher

Abstract: Introduction: Pain is a common comorbidity of conditions such as peripheral nerve injury, substance-induced neuropathy, and trauma. Nearly 1.5 billion people worldwide suffer from chronic pain with the estimated cost of health care nearly $275 billion. The mechanisms of neuropathic pain are poorly understood and its evaluation in humans is complex because most stimuli required to induce neuropathic pain produce irreversible damage. Recent evidence suggests that the incidence of chronic phantom limb pain can be regulated by delivering sensory feedback that is relevant to the amputated limb. This study aims to determine whether cervical spinal root stimulation to elicit sensations localized to the amputated arm can also result in concomitant changes in PLP

Methods: All procedures were approved by the University of Pittsburgh Institutional Review Board and the US Army Human Research Protection Office. Two study participants were implanted with three 8 or 16 contact spinal cord stimulation leads (Boston Scientific) in the lateral epidural space of the cervical spinal cord. Stimulation electrode, amplitude, frequency and pulse width were varied across trials. The location, intensity and modality of the evoked percepts was recorded. The intensity of PLP was recorded on a visual analog scale (VAS) after every stimulation trial. Additionally, the McGill Pain Questionnaire (MPQ) was administered on a weekly basis, and again one month following explantation. The leads were explanted after 2-4 weeks.

Results: A total of 1,493 trials evoked localized sensations, of which 580 PLP episodes were reported (38.9%) at a mean intensity of 2.5 ± 1.9 on the VAS. For the 115 electrodes that evoked a sensation, stimulation amplitude and pulse width were related to the intensity and incidence of PLP respectively. Furthermore, a clinically significant (>5 points) reduction in PLP was observed on the MPQ in subject 1 (9 points) and subject 2 (8 points) at 1-month follow-up. Additionally, the effect of stimulation electrode location on PLP modulation as well as the correlation between the modality of stimulation evoked non-PLP sensation and the incidence of PLP is being explored.

Conclusion: This study suggests that stimulation amplitude and pulse width may modulate the intensity and frequency of a PLP episode. We further observed time-dependent PLP modulation such that the immediate post-stimulation phase was associated with increased PLP that may be coupled to a long-term reduction in PLP.

Theme: Upper Limb Prosthesis Device Design

Poster Title: A Comparison of Training Approaches for Pattern Recognition based Myoelectric Control

Authors: Kadie Wright, Erik Scheme and Kevin Englehart

Abstract: Decades of advancements in the development of myoelectric signal processing techniques have made prosthetic devices an effective means of functional replacement for major upper limb amputees. One of the control approaches that has been widely researched in this field is pattern recognition (PR) based control using electromyography (EMG) signals, which has only recently become commercially available. One challenge to its widespread clinical adoption to this point may be due to the need for training of the PR controller, which requires appropriate collection of example data. Although the inclusion of confounding factors (such as varying limb position) in the training data has been shown to significantly improve the performance of the pattern recognition approach, little work has focused on how to actually elicit the training contractions themselves.

This work examined two existing training techniques that are currently being used in the field (ramp contractions, and velocity guided training), and introduces two new alternative training methods; position guided training and a hybrid position and velocity approach. The comparison of approaches was motivated by a desire to incorporate more dynamic motion into the training process, which may better reflect the actual use case than existing methods and be more intuitive for users. It was hypothesized that more relevant training data would result in improvements in real-time performance and usability in a virtual target acquisition task.

Fourteen able bodied subjects (10 male and 4 female, mean age 24 +/- 2.2 years) completed a Fitts' Law based usability study using controllers trained with each of the training methods. For each method, EMG data representative of five different motions (hand open, hand close, wrist pronation, wrist supination, and no motion) were recorded and used to train the controller, before completing 24 repetitions of the target acquisition task.

Comparison of real-time performance metrics showed no significant difference between the ramp, position and hybrid approaches. Velocity guided training, however, as used in the previously reported prosthesis guided training, obtained significantly better movement efficiency ($p<0.05$). No significant differences were found in the Fitts' law summary metric throughput. These results suggest that, although other training approaches may offer more intuitive training prompts, the currently employed velocity guided training more effectively informs the training of pattern recognition based myoelectric control. Future work will include consideration of cognitive load and motivation on the part of the user, in order to help form a more complete picture of training and usability.

Theme: Other

Poster Title: High-density EMG for simultaneous multiple myosite visualization and identification for myoelectric prosthesis fitting

Authors: Damini Agarwal, Sapna Kumar, Rahul Kaliki and Nitish Thakor

Abstract: Myosite location is one of the most important steps in the process of myoelectric prosthesis fitting. This is because identification of the best locations for electrode placement governs the quality of EMG signals and the subsequent performance of control algorithms [1-2]. The process requires precision, even for two-site based direct control systems that use antagonistic muscle groups. The current industry standard is to manually palpate the residual limb while the patient performs a contraction to identify broad areas of muscle movement and then to use a differential electrode system for finer identification of myosites [3-4]. Shifting an electrode even by <1 cm over the muscle causes significant changes in sEMG amplitude subsequently affecting the quality of control [5-7]. The time required as well as the reliability of this process is solely dependent on the skillset of the prosthetist, thus making it a highly specialized procedure.

New control strategies such as pattern recognition [8-12] use up to eight EMG sites for signal acquisition. In the case of above elbow patients, all eight of these electrodes need to be placed in specific locations on the residual limb to maximize information content of each channel. With these emerging control strategies, the problem of myosite identification becomes increasingly difficult over traditional two-site direct control systems. Thus, there is a significant need to improve upon the traditional brute force method of myosite location.

We have developed a novel flexible High-Density EMG [13-18] array to "image" a patient's residual limb prior to socket fabrication. This system generates muscle activity maps from 128 channels of simultaneously recorded monopolar EMG signals. The muscle activity maps provide a visual means of identifying all potential myosite locations for a given contraction. Moreover, by analyzing different muscle activity maps for different hand motions and contractions, it is possible to determine the most unique combination of sites that provide differentiable patterns for control.

Use of this HD-EMG interface allowed for optimized identification of eight myosites for pattern recognition-based prosthesis fitting of a patient with a transhumeral amputation. Interestingly, in this case study, we identified unique EMG sites where there was little visually identifiable movement of the residual limb. Such sites would likely be missed by traditional myosite selection methods. Using the selected sites, the patient was subsequently successfully fit with a pattern recognition prosthesis. Thus, HD-EMG is a valuable myosite visualization and identification tool that augments the prosthetists' skillset in myosite location.

Theme: Occupational Therapy & Outcome Measures

Poster Title: Case Study: Bilateral arm transplant patient and use of prosthetic devices to promote independence after transplant.

Authors: Joe Butkus and David Beachler

Abstract: Case Study: Bilateral arm transplant patient and use of prosthetic devices to promote independence after transplant.

The prevalence of arm transplantation, due to medical advances, has been increasing in recent years. Successful limb transplantation requires balancing of many issues, to include: extensive rehabilitation, medical management, financial support, availability of a caregiver and a tolerance for a decrease in functional abilities for some length of time. Patients agree to a period where they will have much less function than they were with prosthetic limbs that can last from 6 months to 18 months of limited function. After transplantation, it can be 6 months before a gentle functional pinch begins to emerge. This time commitment and extended period of decreased function complicates the patient's everyday life and the decision process for potential patients.

This presentation will examine the adaptations post transplantation and prosthetic options trialed to assist in activities of daily living for one transplant patient. Treatment course and collaboration between prosthetists and occupational therapists will be reviewed as the function of the hands changed as well as development of a prosthetic limb evolved. Other adaptations to the environment will be reviewed to educate participants in other ways to achieve success despite having hand or prosthetic control issues. Prosthetic options offer much faster path to a functional grasp and more intimate interaction with their environment.

The case review will serve to educate and illustrate issues and that arose during the first year of treatment. This review will help medical practitioners understand these options and find ways to promote greater independence at an earlier point in care. Patients can benefit from the return to some assistance from a prosthetic if they are willing to tolerate the time and effort involved. Achieving independence with all required daily tasks is the overarching goal and working to combine technologies can assist in that effort. These adaptations and combination of technologies will serve to improve the participants patient problem solving across a variety of other injuries.

Theme: Sensory Feedback

Poster Title: Force Sensing Prosthetic Finger Tip using Elastomer-Embedded Commodity Infrared Proximity Sensor

Authors: Jacob Segil, Radhen Patel, Yanyu Xiong, Marie Schmitt, Richard Weir and Nikolaus Correll

Abstract: The field of upper limb prosthetic design seeks to recreate what was lost after amputation including the loss of sensation. In order to accomplish this feat, prosthetic devices require compact, stable, and clinically robust sensors in order to measure interaction with the external environment. These types of sensors are more important now since dramatic progress was made to provide stable natural touch perception using implanted neural interfaces. We developed a force sensing prosthetic fingertip using elastomer-embedded commodity infrared proximity sensor to enable sensory restoration after upper limb amputation.

The fingertip sensor integrates a commodity infrared proximity sensor (VCNL 4010, Vishay Semiconductors) which is embedded in a soft polymer, polydimethylsiloxane or PDMS (Dow Corning Sylgard 184). The infrared sensor was chosen due to its small form factor (3.95 x 3.95 x 0.75 mm3) which includes all digital electronics to produce a I2C communication output signal. The polymer was chosen due to its ease of manufacturing/molding and resistance to chemical and mechanical abrasion. The sensor operates by emitting infrared light (890nm) through the PDMS layer and measuring the net reflected intensity of the reflected signal. A layer of copper was deposited onto the PDMS material in order to reflect IR light and create a measurement which is independent of the reflectivity of the object in contact with the sensor. The intensity is approximately inverse of the square of the distance traveled and therefore can be used to determine displacement of the PDMS layer. Then, Hooke's law indicates the force and thereby creates a compact, stable, and clinically-robust force sensor for prosthetic fingers.

The mechanical design of the fingertip involved reverse engineering a commercially available prosthetic finger (Bebionic 2, RSL Steeper) into a computer-aided design (CAD) file. The CAD file was then modified in order to embed the printed circuit board of the sensor as well as pathway for the four-line ribbon cable. The fingertip was then manufactured using a plastic rapid prototyping printer (Objet Connex 350). Afterwards, a molding process created the PDMS layer which ensures that any contact force (i.e. - oblique or non-normal forces) will be detected by the sensor.

A force sensing prosthetic finger was developed in order to create a compact and stable measuring method to promote the restoration of tactile sensation for people with upper limb amputation.